

VOLUME 1  
THE SURFACE  
CLIMATE OF  
1963 and 1964

# METEOROLOGICAL ATLAS of the International Indian Ocean Expedition



NATIONAL SCIENCE FOUNDATION • WASHINGTON, D.C. • SEPTEMBER, 1972





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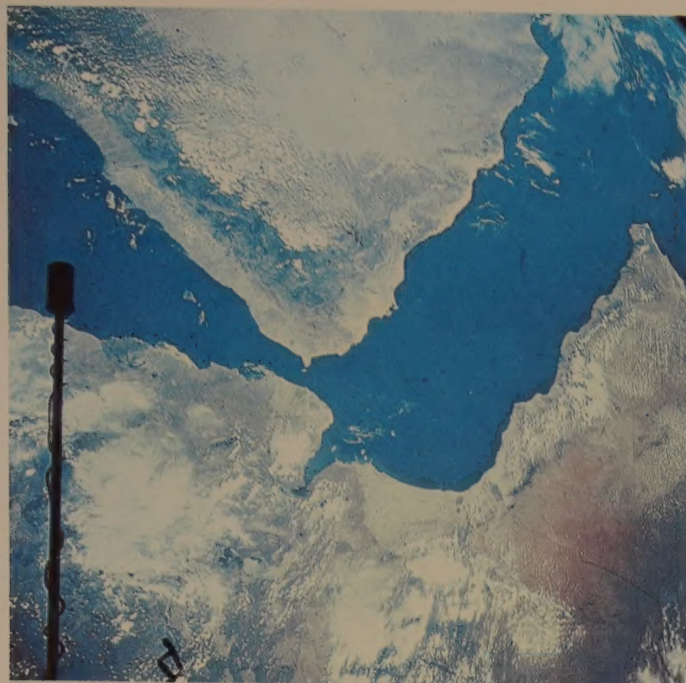












GEMINI XI SEPTEMBER 14, 1966

The Red Sea is at the left. From it the Gulf of Aden extends to the Indian Ocean on the horizon. Between the spacecraft and the V-shaped Tadjoura Gulf in the lower center of this photo is Lake Abbe. The boundary between Ethiopia and the Somali Republic crosses that lake. Yemen occupies the left part of the Arabian Peninsula shown here, and Aden is along the shore to the east. Major structural lineaments of the Arabian shield, and the dendritic wadi system of the Hadramawt Plateau, can be observed.



GEMINI XI SEPTEMBER 14, 1966

This panoramic oblique view from over the Indian Ocean embraces nearly the whole Arabian Sea. The horn of Africa and part of Dhufar, and Muscat and Oman are at the left. On the right the view extends past Pakistan, and well down the coast of India. The low-level wind was southwest in the foreground and northwest off India south of the Gulf of Cambay. The Gulf of Oman is near the upper left. South of it one can see the archlike structure of the Oman Range, and to the north the general trend of the Makran range in Iran is visible. The relationship between these mountains has long been an enigma.



GEMINI XI SEPTEMBER 14, 1966

This picture includes all of Ceylon, yet the Himalayas, roughly 2300 miles away, are faintly visible on the horizon. Ceylon is 270 miles long. Its people are clustered on the moist southwestern third of the island. Dry areas elsewhere were irrigated and productive 2000 years ago, but later were neglected until recent times. At the upper right, cirrus clouds can be seen streaming westward toward Ceylon from a convective area in the Bay of Bengal. At top center there is another region of cloudiness near Calcutta. It is associated with a weak depression.



GEMINI XII NOVEMBER 14, 1966

This view northward over the Bay of Bengal shows the Irrawaddy River delta in Burma. The Gulf of Martaban in the lower right is 150 miles wide, and some of the river's several mouths are visible left of it. Rice is grown on the alluvial lowlands of this fertile delta. The brown, silt-laden water being discharged into the Andaman Sea is evidence of denudation upstream that has been estimated to be 1 foot in 400 years. At the left the northern part of the Andaman Islands can be seen. Cumulus streets prevail over the bay and sea, but there are also a few scattered cirrus clouds.



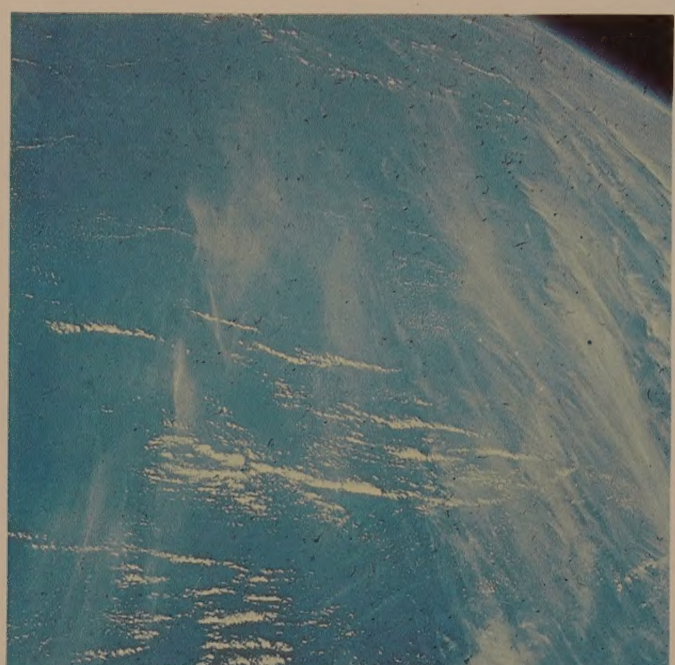
GEMINI IX JUNE 6, 1966

The coastal strip shown is part of the Somali Republic. The Equator crosses this area from the upper left to the lower right. Here the sea-surface temperature in the Somali Current is about 79° F in June, and you see fewer clouds over the water than over the land. The convective cloudiness covers the coastal lowlands and extends into northeastern Kenya, but over the highlands at the upper left—the region between the Indian Ocean and Lake Victoria—the sky is mostly quite clear.



GEMINI X JULY 21, 1966

Suvadiva is the large atoll here, Addu Atoll is below it, and the small island and reef of Fua Mulaku Island is between them. Within the lagoon of Suvadiva, the white spots are cumulus clouds, and the dark ones are coral knolls typical of Pacific and Indian Ocean atoll lagoons. The white, pearl-like fringe on the shores of both Suvadiva and Addu is the reflectance from strong surf produced as waves approach from the south. The prominent large white cumulonimbus in the foreground had reached the upper levels of the atmosphere, and the tops of these clouds were being blown to the southwest when this picture was taken.



GEMINI X JULY 21, 1966

This picture shows a thin veil of cirrus clouds being swept along by high-altitude east winds over the Indian Ocean south of Ceylon. The camera was pointed west, and the Maldiv Islands are near the horizon, but too small and far away to be seen. Thunderstorms spew out long cirrus streamers which may extend for hundreds of miles in this tropical region. A different, lower level wind regime had aligned the cumulus clouds in the foreground in a north-south line at the time this picture was taken.



GEMINI XI SEPTEMBER 14, 1966

This view eastward across Sumatra shows the great quantities of cirrus produced by cumulonimbus clouds in this equatorial monsoon climate. The intense convective activity, which produces more than 100 inches of rain a year in much of this area, is particularly evident over northern Sumatra in the upper left, and along a line which cuts across the lower right corner of the picture. In the lower levels the undeveloped cumuli show open cellular patterns in some areas, as well as a suggestion of a vortex in the right center of the photo. Monthly mean temperatures average about 80° F at sea level in this part of Indonesia.



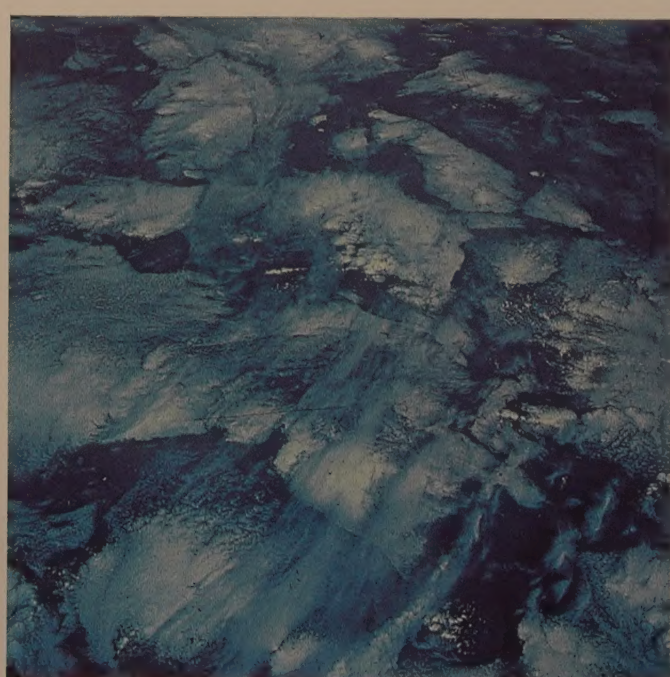
GEMINI VI DECEMBER 16, 1965

The Mayotte Archipelago is in the Mozambique Channel between Africa and the Malagasy Republic. This is a westward view of the Comoro Islands there. At the lower left is Mayotte, surrounded by an extensive, dangerous coral reef. In the center is Anjouan, which has a central peak 5170 feet high. Moheli, directly above it, is the smallest of these volcanic islands. Grande Comore is at the upper right, but covered by cumulus congestus clouds. The varied alignment of cumulus indicates a complex low-level wind pattern. A small cloud eddy induced by the light flow of air past the islands can be seen near the top of the picture.



GEMINI VI DECEMBER 16, 1965

This is an eastward look at the southern edge of a tropical vortex seen over the waters of the southern Indian Ocean. The alignment at different altitudes shows the changes in the wind direction with height. Of particular interest here is the apparent alignment of the lower clouds. This suggests that there was a diverging northeasterly flow, but because such a flow is not likely so near to storms, the apparent alignment may have resulted from the perspective of the photograph.



GEMINI IX JUNE 6, 1966

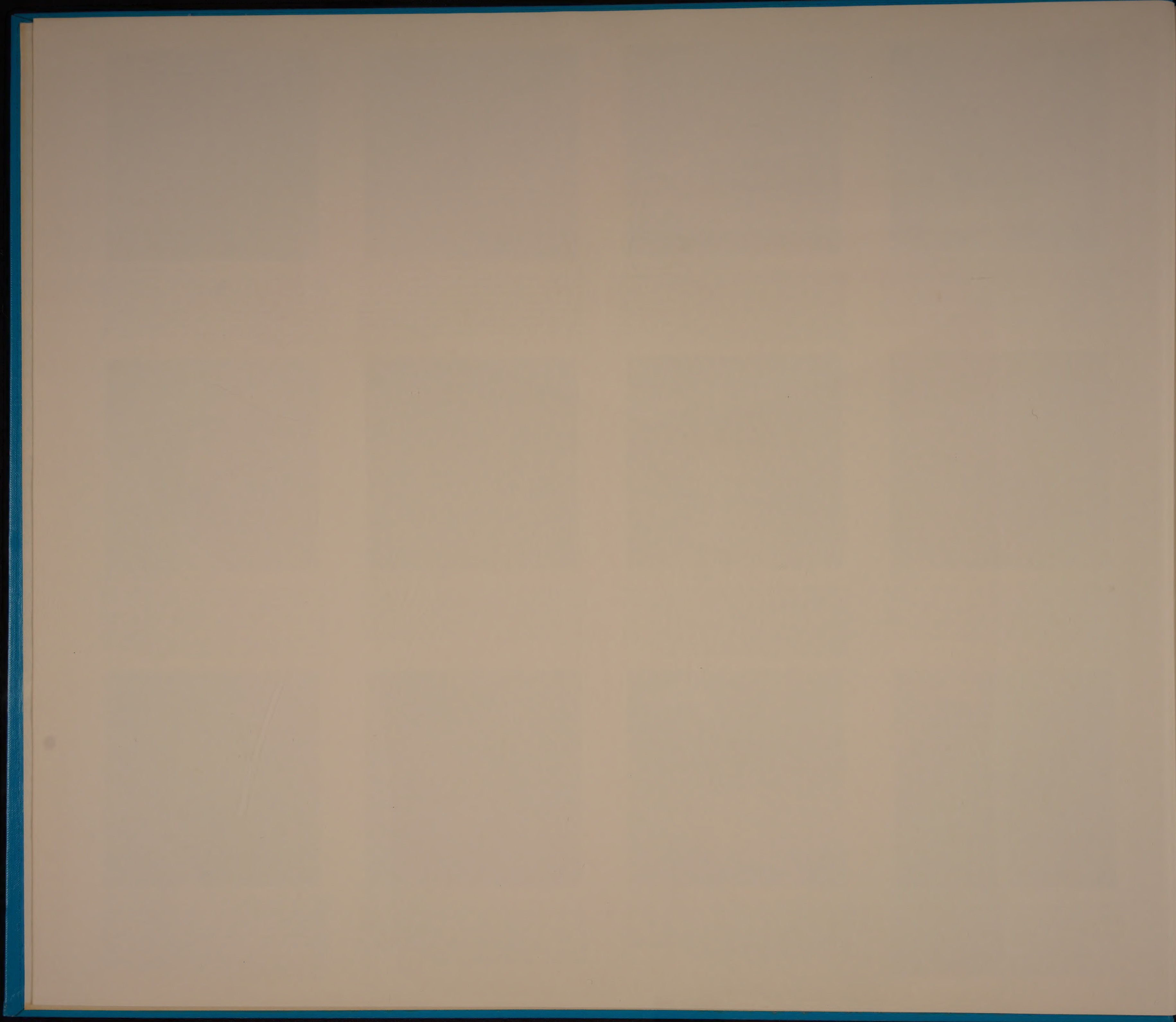
These stratocumulus clouds seen over the southeastern Indian Ocean looked like floating fields of ice, but the orbits of the Gemini flights kept them well away from the polar regions of the Earth. Similar cloud forms frequently are seen off the coasts of California and Peru where the waters of the Pacific are relatively cool. Some cellular patterns are discernible in this stratocumulus, indicating that a Bénard cell-type circulation might be found in the lower atmosphere. A few cirrus clouds also are scattered throughout the photo.



GEMINI XI SEPTEMBER 14, 1966

This is a wide-angle photo of Australia's northwestern coast with Eighty Mile Beach in the foreground. Inland is the Great Sandy Desert; the Lake Mackay is near the center of the right edge. In the upper left, parts of Timor are visible despite dense clouds such as persist over Indonesia much of the year. The Gulf of Carpentaria is near the horizon on the right. Cumulus-cloud patterns cover hilly regions below it. A vast Precambrian shield extends across Australia from Perth to the Gulf of Carpentaria. The area is a broad complex of pillow lavas, tufts, and greenstones, flanked by metasediments, all of which are intruded by granites.









VOLUME 1

**METEOROLOGICAL**  
**ATLAS of the**  
**International**  
**Indian Ocean**  
**Expedition**

**The Surface Climate  
of 1963 and 1964**

by  
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## Preface

The International Indian Ocean Expedition which lasted from 1959 to 1965 was a multinational, multidisciplinary attempt to study and possibly explain the physical and biological characteristics of the "monsoon" ocean. Meteorologists were active during the Expedition, collecting countless observations from ships, landstations, aircraft, and satellites.

Under the auspices of the Intergovernmental Oceanographic Commission of UNESCO, a series of Expedition Atlases is being published including a two-volume meteorological atlas.

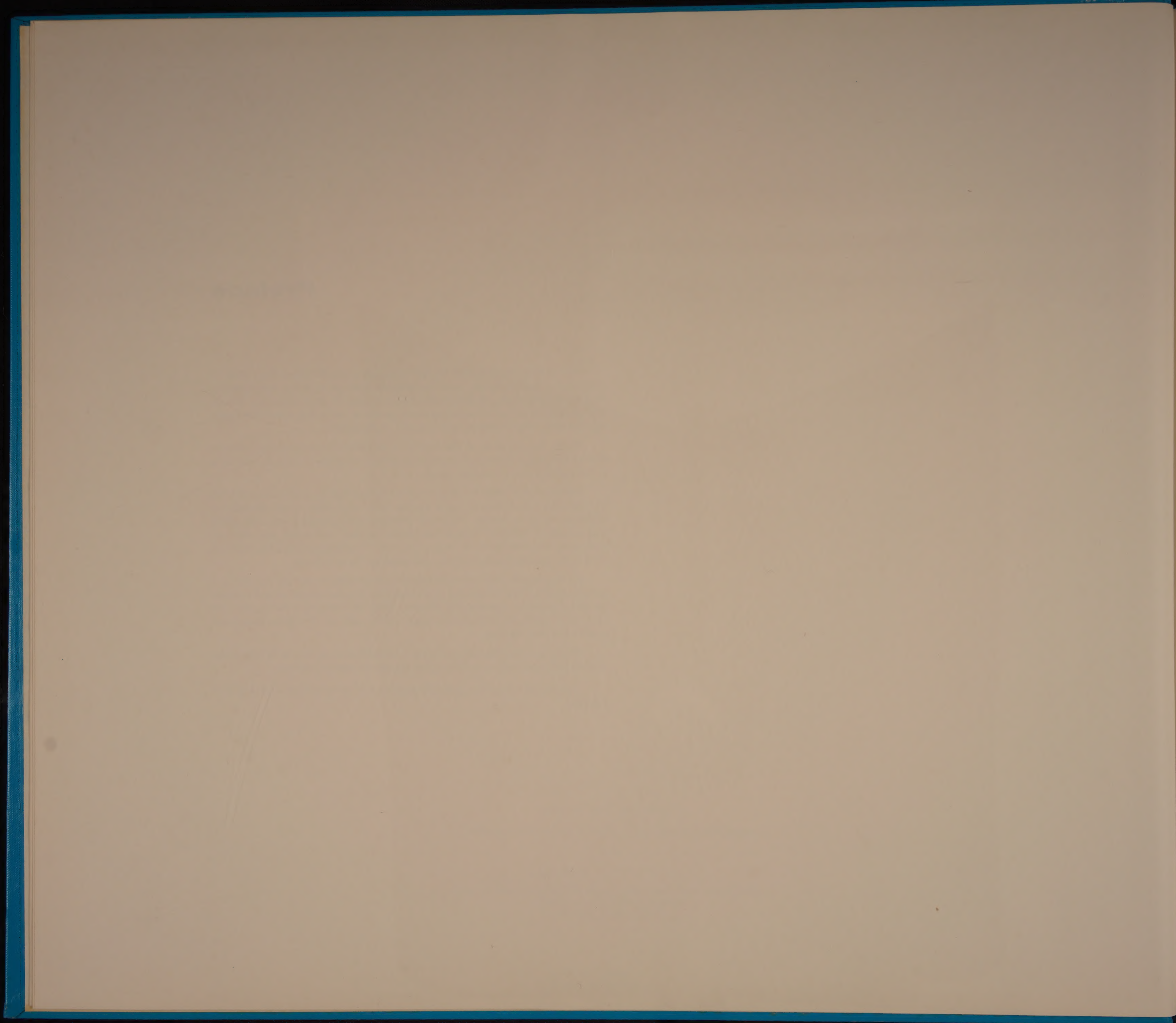
Volume 1 describes the climate of the Indian Ocean as determined from 194,000 ship observations made during 1963 and 1964, when Expedition activity was at its height. From the observations, averages—by individual month and by 5-degree latitude-longitude "square"—of wind, pressure, air and sea surface temperature, vapor pressure, clouds, precipitation, and heat exchange, together with analyses, are depicted on 144 charts.

Meteorologists and oceanographers will be able to use the volume as a background to detailed studies, enabling them to relate physical and biological distributions to the monthly climate. Also, by comparing the charts with long-term meteorological atlases, they will be able to determine significant departures from normal.

Projection (Mercator's) and scale (1:40 million) conform to World Meteorological Organization specifications for meteorological atlases.

Contribution No. 72-1 of the Department of Meteorology, University of Hawaii.







## Acknowledgements

We are happy to acknowledge the many individuals and organizations contributing to this volume. Of fundamental importance are the weather observations made by officers of merchant ships and by technicians aboard research vessels. Meteorological services collected observations, disseminated them by radio, transferred them to punch cards, and mailed copies to us.

Officials of three organizations continuously helped and encouraged us: Drs. E. G. Droessler and F. D. White successively Head of the Atmospheric Sciences Section of the U.S. National Science Foundation; Mr. P. R. Krishna Rao, Mr. C. Ramaswamy, and Dr. L. S. Mathur successively Director-General of the India Meteorological Department, and Dr. W. S. Wooster and Dr. K. N. Fedorov successively Director of the Office of Oceanography, UNESCO. The World Meteorological Organization, directly and through its administration of U.N. Special Fund support, and the U.S. National Aeronautics and Space Administration contributed in many ways; the counsel of Dr. K. R. Ramanathan was invaluable.

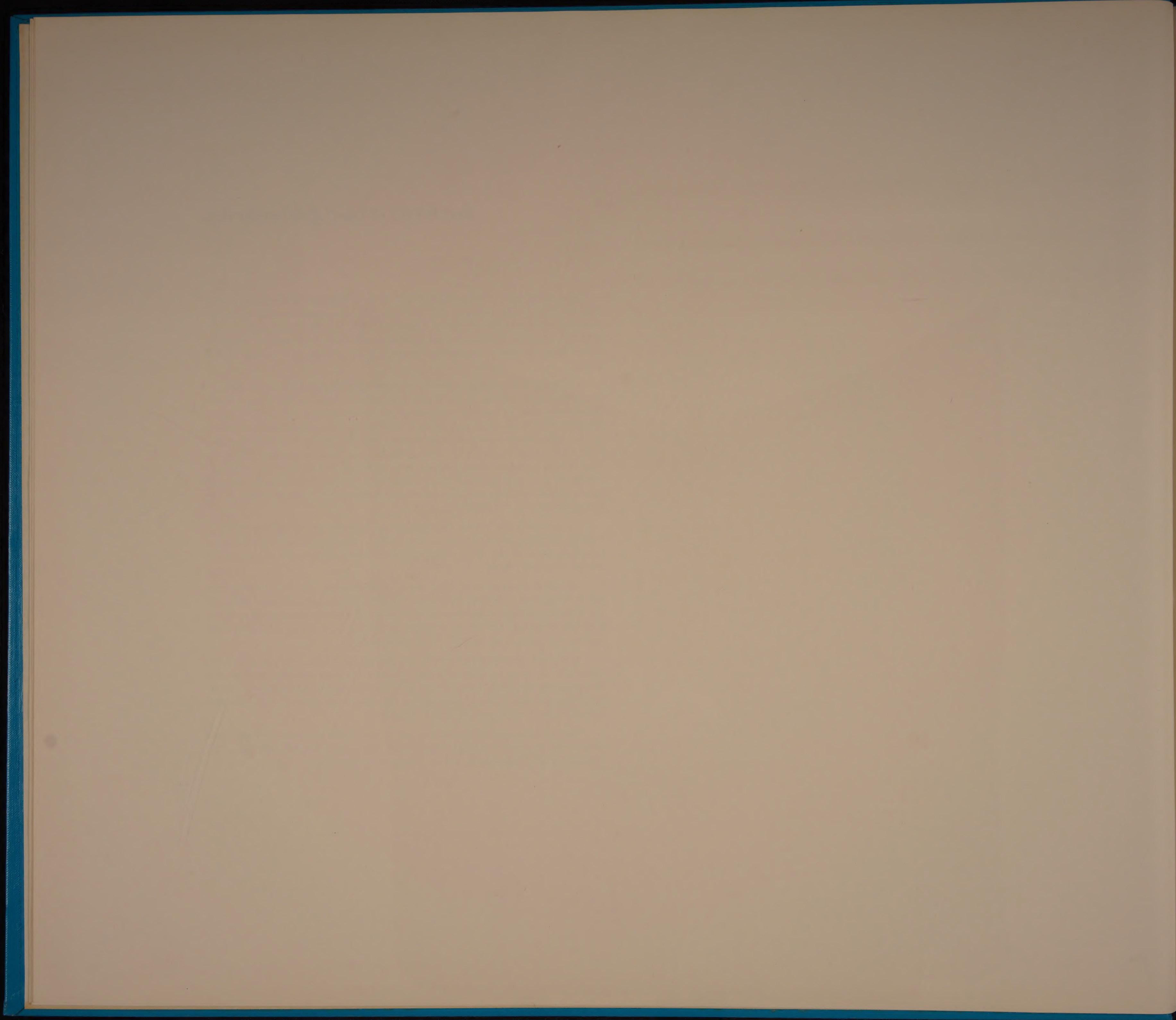
In our preliminary work, undertaken at the International Meteorological Center, Bombay, we owe much to Mr. C. R. V. Raman, Director of IMC and his staff. Most of the ideas incorporated in this volume were developed in discussions with them.

At the University of Hawaii, Mr. J. R. Nicholson, Mr. J. C. Sadler, and Mr. F. P. Ho and scientists at the University Computing Center gave valuable professional advice, while the work of Mrs. M. Hamao (typing), Mrs. E. U. McAfee (editing), Mr. R. R. Rhodes (drafting), and Mrs. J. Heavenridge (production planning) was of the highest quality.

Mr. H. W. Holmerud of Stromberg Datagraphics, Inc., investigated the feasibility of using a cathode ray-tube process for data printing; with advice and programming help from Mr. A. F. Brady of California Computer Products, Inc., we were able to arrange for the data to be plotted on a Calcomp 718 machine at Camp H. M. Smith, Honolulu.

The Atmospheric Sciences Section of the National Science Foundation supported preparation of the Atlas under NSF Grant GA-386 and Mr. J. C. Holmes of the Foundation was in charge of publication.







# Introduction

The International Indian Ocean Expedition (IIOE) embodied an unprecedentedly massive effort to explore, describe, and understand the physical, chemical, and biological interactions in a sizable fraction of the water-atmosphere realm of the world (UNESCO, 1965- ). Although surveys were begun in 1957 and research vessels were still probing at the end of 1965, activity was concentrated in 1963 and 1964. The meteorologists, working from their Bombay base at the International Meteorological Center (IMC)<sup>1</sup> selected 1963 and 1964 for a series of special studies of air-sea interactions and synoptic-scale features, using buoys, radiometric recordings, and long-range research aircraft (Ramage, 1965). Investigators need to view results from the oceanographic cruises and the special meteorological studies in an overall meteorological framework before attempting to generalize their conclusions, and an atlas can best provide that framework. Thus, the Intergovernmental Oceanographic Commission, at its Fourth Session (from 3 to 12 November 1965) appointed the senior author as editor, with the task of preparing a two-volume International Indian Ocean Expedition Meteorological Atlas. Representatives of India, the United Kingdom, and the USSR were to constitute an Editorial Advisory Board. In August 1966 the United Kingdom appointed Mr. J. G. Cottis to the Board.

Volume 1 describes the surface climate of the Indian Ocean during 1963 and 1964; Volume 2 describes the upper-air climatology, using all available data through 1966.

Compilation of material for Volume 1 proceeded concurrently with the meteorological experiments. IMC and subsequently the Department of Geosciences, University of Hawaii, collected, punched on cards, and checked 194,000 standard weather observations made by ships of all types voyaging in the Indian Ocean during 1963 and 1964. From these observations, averages by individual month and by 5-degree latitude-longitude squares<sup>2</sup> of wind, pressure, air and sea surface temperature, vapor pressure, clouds, precipitation and heat exchange, together with analyses, are depicted on 144 charts in Volume 1. The investigator may readily determine departures from the long-term means by comparing the charts with excellent published atlases (van Duijnen Montijn, 1952; U.S. Weather Bureau, 1957; Meteorological Office, 1949; Deutsches Hydrographisches Institut, 1960; McDonald, 1938). Ramage (1969) discusses important features depicted in the charts.

## GENERAL PLAN FOR CHARTS

The series "Marine Climatic Atlas of the World," published by the U.S. Navy, comprises seven volumes covering every ocean (Volume III (1957)

<sup>1</sup> Established and operated by the India Meteorological Department with help from the United Nations (WMO) Special Fund and the U.S. National Science Foundation.

<sup>2</sup> Over most of the ocean, data were insufficient to allow averaging for smaller areas.

describes the Indian Ocean). To facilitate comparison we have used the same projection (Mercator's) and scale (1:40 million) for the surface and constant pressure-level charts as were used in the Navy Atlas. This projection and scale conform to specifications for marine climatic atlases as laid down by the World Meteorological Organization (1960).

The charts in Volume 1 encompass the Indian Ocean south to 45°S. Beyond this latitude very few ship observations were made in 1963 and 1964.

## DATA SOURCES

### SHIP OBSERVATIONS

Ships, whether merchant, naval, or research, make and record surface weather observations in international code (WMO FM 21C or 23C), transmit the information to the nearest shore radio station, and on reaching home ports mail their weather logs to their national meteorological services.

At the International Meteorological Center in Bombay, we obtained reports passed by nearby ships through Bombay radio, reports included in broadcast collections from Indian Ocean meteorological centers, and, a few weeks later, original or "hard" copies of these same broadcasts. After the end of the 1963, 1964 observing period when collection had shifted to Honolulu, information extracted by meteorological services from ships' weather logs began arriving. Australia, France, Japan, the Netherlands, and the U.S. Navy supplied data on punch cards or as print-outs. Collection proceeded slowly through February 1967, but the information was worth waiting for. Over much of the central Indian Ocean, ships cannot easily contact shore radio stations and so their reports do not appear in broadcast collections.

Approximately 12 per cent of the observations were recorded in the "SHRED" or short message form (FM 23C) which does not include dew point or air-sea temperature difference.

All the observations were transferred to punch cards with a single format based on code FM 21C. Many hours would have been saved had all countries already agreed on a single format.

### MID-OCEAN ISLAND OBSERVATIONS

The smallest coral speck distorts its oceanic environment to some extent and so weather observations made from it are never quite representative. Nevertheless, the information, if treated critically, can be valuable. Table 1



lists small islands at which at least one meteorological variable is probably representative of open-ocean conditions. Averages of the representative variables can be usefully compared with averages determined from ship observations (see page ix).

TABLE 1: Small Islands with Weather  
Representative of Open-Ocean Conditions

| Station<br>Number |                          | Latitude  | Longitude | Representative<br>Variables |   |   |   |   |  |
|-------------------|--------------------------|-----------|-----------|-----------------------------|---|---|---|---|--|
| 43311             | *Amini Divi              | 11° 07'N; | 72° 44'E  | 1                           | 2 | 4 | 5 | 6 |  |
| 43367             | Car Nicobar              | 09° 10'N; | 92° 50'E  |                             | 2 | 4 |   | 6 |  |
| 43369             | *Minicoy                 | 08° 18'N; | 73° 00'E  | 1                           | 2 | 4 | 5 | 6 |  |
| 41350             | *Gan                     | 00° 41'S; | 73° 09'E  | 1                           | 2 | 4 | 5 | 6 |  |
| 63980             | Mahé (Seychelles)        | 04° 37'S; | 55° 27'E  |                             |   | 4 |   |   |  |
| 61967             | *Diego Garcia            | 07° 14'S; | 72° 26'E  | 1                           | 2 | 4 | 5 | 6 |  |
| 96995             | *Christmas               | 10° 25'S; | 105° 40'E | 1                           | 2 | 4 | 5 | 6 |  |
| 61974             | *Agalega                 | 10° 33'S; | 56° 45'E  | 1                           | 2 | 4 | 5 | 6 |  |
| 61968             | *Glorieuses              | 11° 33'S; | 47° 17'E  | 1                           | 2 | 4 | 5 | 6 |  |
| 96996             | *Cocos                   | 12° 05'S; | 96° 53'E  | 1                           | 2 | 4 | 5 | 6 |  |
| 61976             | *Serge-Frolov (Tromelin) | 15° 53'S; | 54° 31'E  | 1                           | 2 | 4 | 5 | 6 |  |
| 61986             | *St. Brandon             | 16° 27'S; | 59° 33'E  | 1                           | 2 | 4 | 5 | 6 |  |
| 61988             | Rodriguez                | 19° 41'S; | 63° 25'E  |                             | 2 | 4 |   | 6 |  |
| 61996             | New Amsterdam            | 37° 50'S; | 77° 34'E  |                             | 3 | 4 |   | 6 |  |

1. wind; 2. pressure; 3. air temperature; 4. vapor pressure; 5. cloudiness; 6. precipitation frequency.

\* Coral island.

WEATHER-SATELLITE OBSERVATIONS

During 1963 and 1964 the weather satellites TIROS VII, TIROS VIII, and NIMBUS I were orbiting. Table 2 summarizes the program (National Aeronautics and Space Administration, 1966) which is detailed on Charts 1 to 24.

TABLE 2: Weather Satellites Orbiting in 1963 and 1964

| Satellite  | Period of Operation                 | Data Used in Atlas                                                                       |
|------------|-------------------------------------|------------------------------------------------------------------------------------------|
| TIROS VI   | 1 January - 11 October 1963         | TV pictures                                                                              |
| TIROS VII  | 19 June 1963 - 31 December 1964     | (1) TV pictures<br>(2) 8.0 - 12.0 micron<br>radiometer<br>measurements                   |
| TIROS VIII | 21 December 1963 - 31 December 1964 | TV pictures                                                                              |
| NIMBUS I   | 28 August - 22 September 1964       | (1) TV pictures<br>(2) High resolution<br>3.5 - 4.1 micron<br>radiometer<br>measurements |

ERROR CHECKING

For each month, the ship observation-card deck was machine-sorted into 5-degree blocks in ascending order of latitude and longitude. Duplicate cards were then removed.

ERROR IDENTIFICATION

Errors in observation, coding, transmission, and punching were discovered through a computer program which compared each variable with the corresponding 5-degree square climatology (van Duijnen Montijn, 1952). Any variance in the pressure, air and sea temperature greater than one standard deviation, or any inconsistency among variables (e.g., low-cloud amount greater than total-cloud amount) was printed out and the card identified.

ERROR REMOVAL

Many obvious errors were detected and incorrect cards replaced. In some cases errors could be corrected by referring to other observations in the same general location for the same time period. Rather than delete an entire observation with one wrong variable, we replaced the erroneous value by 99 on a new card with the remainder of the observation left unchanged. Ninety-nine signified missing data.

Error checking contributed 5 per cent to the usable observations, which comprised 95 per cent of all those received.

DATA PROCESSING AND ANALYSIS

All checked and corrected ship observations were stored on magnetic tape.

AVERAGING

The computer averaged each meteorological variable as well as the positions of all the observations for each of the twenty-four months for each 5-degree square. Table 3 shows that the observations are evenly distributed among the four synoptic observing hours.

PLOTTING AND PRELIMINARY ANALYSIS

A Benson-Lehner digital plotter then automatically printed on a base map each 5-degree-square average at the average observation position within the square. In 5-degree squares without data, the long-term averages (van Duijnen Montijn, 1952) were entered.

Some 5-degree squares contained over 100 observations, some a few observations covering only one or two synoptic events, and the remainder only the long-term means (see Table 3). This non-uniformity required that a skilled analyst make rapid preliminary analyses. After first drawing



TABLE 3: Temporal Distribution of Ship Observations

|                      |   | J     | F    | M    | A    | M    | J    | J    | A    | S     | O    | N    | D    | Y    |        |
|----------------------|---|-------|------|------|------|------|------|------|------|-------|------|------|------|------|--------|
| No. of observations  | } | 1963  | 5754 | 5394 | 6076 | 8049 | 7708 | 8576 | 8411 | 9167  | 7838 | 8483 | 7532 | 6854 | 89842  |
| % with sea temp.     |   |       | 84   | 84   | 85   | 82   | 79   | 80   | 79   | 81    | 82   | 81   | 79   | 77   | 81     |
| No. of observations  | } | 1964  | 8309 | 8240 | 7701 | 6370 | 8504 | 9113 | 9573 | 10666 | 9345 | 9348 | 8668 | 8358 | 104195 |
| % with sea temp.     |   |       | 71   | 77   | 83   | 87   | 85   | 85   | 84   | 85    | 85   | 85   | 84   | 85   | 83     |
| % of 5-degree        |   |       |      |      |      |      |      |      |      |       |      |      |      |      |        |
| squares with more    |   | 1963  | 47   | 48   | 48   | 73   | 64   | 69   | 67   | 69    | 64   | 68   | 70   | 61   | 62     |
| than 5 observations  |   | 1964  | 69   | 67   | 65   | 51   | 66   | 65   | 67   | 70    | 66   | 63   | 62   | 61   | 64     |
| % of observations at |   |       |      |      |      |      |      |      |      |       |      |      |      |      |        |
|                      |   | 00GMT | 24   | 23   | 23   | 23   | 24   | 24   | 24   | 24    | 24   | 24   | 24   | 23   | 24     |
|                      |   | 06GMT | 28   | 29   | 29   | 30   | 29   | 29   | 28   | 27    | 28   | 28   | 29   | 28   | 28     |
|                      |   | 12GMT | 27   | 26   | 26   | 27   | 27   | 27   | 27   | 28    | 26   | 27   | 26   | 27   | 27     |
|                      |   | 18GMT | 21   | 22   | 22   | 20   | 20   | 20   | 21   | 21    | 22   | 21   | 21   | 22   | 21     |

isopleths to fit the plotted data, the analyst adjusted the isopleths to allow for data disparity, taking care at the same time to maintain the gradients demanded by the computer averages. The preliminary analyses were then used to adjust values based on few or no 1963, 1964 observations. In general, data were so sparse below 40S, long-term means prevailed.

#### CENTER-POINT PLOTTING AND COMPUTER ANALYSIS

In order to obtain a uniformly spaced grid of averages (including modified averages) for every 5-degree square, a computer method was devised to interpolate the averaged data to the center of each square.

Three values were used in each interpolation, weighted inversely according to their distance from the center point. A value already located at the center of a square was transferred unchanged. Otherwise, if the value within the square was located west and south of the center, then values in the squares east and north of the center contributed to the interpolation, and correspondingly for other locations. No interpolation was attempted near coasts. Next, the central values were machine-smoothed by a "diamond-type" (five-point) interpolation and, finally, the Benson-Lehner plotter, directed by a nine-point quadratic interpolation program, analyzed the charts of all scalar quantities for preselected isopleth intervals. An analyst drew the streamlines on charts of mean resultant wind direction.

#### FINAL ANALYSIS

Computer analysis near the coast is very difficult to program, so again the analyst intervened. After a last check on time and space continuity, he was finished and passed the charts on to the draftsman.

#### ISLAND STATIONS

Averages of representative variables observed at the standard synoptic hours at selected island stations (Table 1) were plotted on the appropriate charts. Although not incorporated in the analyses, these values contribute useful information.

#### AVAILABILITY OF 1963 AND 1964 DATA

Some investigators will wish to make their own analyses and interpretations of the 1963, 1964 observations and, possibly, to compare them with the long-term means. From

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2525 Correa Road  
Honolulu, Hawaii USA 96822

they can obtain at cost, checked and corrected synoptic observations made from ships and the selected islands during 1963 and 1964 and the averages listed in Table 4.

These data can be supplied on magnetic tape, punch cards, or microfilm.

#### INDIVIDUAL CHARTS

On each chart, only two sets of isopleths can be conveniently displayed, whereas more than two variables were averaged. Thus, to facilitate atlas users making their own analyses, all the averaged variables have been printed on the charts. Since entering the data by typesetting or drafting



TABLE 4: Monthly Means Available on Request

| Variable                                                      | 1963-1964              |                           |         | Long-Term           |
|---------------------------------------------------------------|------------------------|---------------------------|---------|---------------------|
|                                                               | Ships                  | 5-Degree<br>Squares       | Islands | 5-Degree<br>Squares |
|                                                               | At Average<br>Position | Interpolated<br>To Center |         |                     |
| Ship position                                                 | x                      |                           |         |                     |
| Observation date                                              | x                      |                           |         |                     |
| Number of observations                                        | x                      | x                         | x       |                     |
| Surface wind:                                                 |                        |                           |         |                     |
| E-W component                                                 | x                      | x                         | x       | x                   |
| N-S component                                                 | x                      | x                         | x       | x                   |
| Speed                                                         | x                      | x                         | x       | x                   |
| Resultant speed                                               | x                      | x                         | x       | x                   |
| Resultant direction                                           | x                      | x                         | x       | x                   |
| Steadiness                                                    | x                      | x                         | x       | x                   |
| Sea-level pressure                                            | x                      | x                         | x       | x                   |
| Temperature:                                                  |                        |                           |         |                     |
| Air                                                           | x                      | x                         | x       | x                   |
| Sea surface                                                   | x                      | x                         |         | x                   |
| Moisture:                                                     |                        |                           |         |                     |
| Dew point                                                     | x                      | x                         | x       | x                   |
| Vapor pressure                                                |                        | x                         | x       | x                   |
| Saturation vapor<br>pressure at temperature<br>of sea surface |                        | x                         |         | x                   |
| Weather:                                                      |                        |                           |         |                     |
| Cloudiness                                                    | x                      | x                         | x       | x                   |
| Frequency of rain                                             | x                      |                           | x       |                     |
| Frequency of thunderstorm<br>manifestations                   | x                      |                           | x       |                     |
| Contributions to heat exchange<br>at sea surface from:        |                        |                           |         |                     |
| 1. Short-wave radiation                                       | x                      | x                         |         | x                   |
| 2. Reflected radiation                                        | x                      | x                         |         | x                   |
| 3. Back radiation                                             | x                      | x                         |         | x                   |
| 1 + 2 + 3                                                     | x                      | x                         |         | x                   |
| 4. Evaporation or condensation                                | x                      | x                         |         | x                   |
| 5. Conduction                                                 | x                      | x                         |         | x                   |
| 4 + 5                                                         | x                      | x                         |         | x                   |
| 1+2+3+4+5                                                     | x                      | x                         |         | x                   |

would have been error ridden as well as unjustifiably expensive, we chose a new method which holds much promise for future atlas design.

The punch card decks previously prepared for the Benson-Lehner curve plotter were transferred with appropriate translation programs to magnetic tape. The tape was then run through a Calcomp 718 plotter which drew the digits of each data cluster around the center of each 5-degree square.

The box in the upper right-hand corner of each chart defines the isopleths, and specifies the numerical data listed in the 5-degree squares and at selected island stations (see Table 1).

The color scheme, line weights, and type sizes and styles have been chosen to provide maximum information with minimum clutter. The more important isopleths spring first to the eye while scrutiny readily reveals all the other data entered on the charts.

Although isopleths extend over the whole ocean, in some areas, with fewer than six observations per 5-degree square, they are based on little more than extrapolation and climatology (see page viii). There, dashed isopleths call attention to data paucity and to uncertain analysis.

BACKGROUND INFORMATION (CHARTS 1-24)

Research vessels and research aircraft were active during 1963 and 1964. Thus, investigators will need to relate the special observations made from these platforms to the climate as determined from the more numerous merchant ship observations. Since the tracks of research vessels, which made regular surface- and upper-air observations and aircraft<sup>3</sup> shown on the charts include the locations at which radio soundings and drop soundings were made, the information could help the users of Volume 2 as well.

Tropical disturbances, particularly hurricanes, may affect the climate of a single month most noticeably by locally increasing the frequency of rain in a normally dry tradewind region or by modifying the sea-surface temperature (Jordan, 1965). The tracks of tropical disturbances (depressions, storms, or hurricanes) plotted on the charts are based on information provided by the India Meteorological Department (northern Indian Ocean), the Mauritius Meteorological Services (western and central southern Indian Ocean) and the Australian Bureau of Meteorology (eastern southern Indian Ocean). Pictures by weather satellites guarantee that no storm is missed, even over regions seldom traversed by ships.

WINDS AND SEA-LEVEL PRESSURE (CHARTS 25-48)

Mean resultant surface winds and mean sea-level pressures appear to be reasonably well aligned (allowing for a frictional effect) even in low latitudes. This is largely because averaging tends to cancel significant ageostrophic components. Convenience and usage dictated the choice of knots to denote wind speed. However, dividing by 2 to obtain m sec<sup>-1</sup> will introduce no detectable error.

<sup>3</sup> Track designations

(a) U.S. Weather Bureau Research Flight Facility. The day of the month is followed by the aircraft designator: A=DC-6A; B=DC-6B; C=WB-57; D=WB-26.

(b) Woods Hole Oceanographic Institution. DC-4 aircraft. W is followed by the day of the month.



Wind steadiness % ((mean resultant wind/mean wind) x 100) is both easier to calculate and gives much the same information as standard deviation. Values determined from few observations are likely to be quite unrepresentative. An investigator can readily calculate the stress of the mean resultant wind or the mean wind from the information presented in each 5-degree square, using in the process his favorite value of the drag coefficient!

#### AIR AND SEA-SURFACE TEMPERATURES (CHARTS 49-72)

Air temperature is measured in such a variety of ways on shipboard that it is pointless to estimate corrections. Improper exposure and radiational heating from the ship probably combine to produce positive errors.

Since authorities disagree on what correction, if any, should be applied to sea-temperature measurements made from merchant ships to obtain the true temperature of the sea surface, we have refrained from making any adjustments to the observations. Miller and Jefferies (1967), tabulate the differences between the mean monthly sea-surface temperatures for 1963 and 1964 and the long-term means (van Duijnen Montijn, 1952). The research vessels ARGO and DISCOVERY recorded sea temperatures as low as 16°C at 10N off the coast of Somalia in August 1964. However, 254 observations in the corresponding 5-degree square averaged 24°C. Thus, the charts cannot depict large gradients in regions of active upwelling.

There were fewer observations of sea temperature than of air temperature (Table 3).

Air and sea-surface isotherms have a confusing habit of nearly coinciding over much of the ocean. Because of this we have analyzed the field of air-sea temperature difference which is widely used in air-sea exchange computations.

#### VAPOR PRESSURE (CHARTS 73-96)

We do not distinguish between wet bulb observations made in shipboard shelters and those made with sling psychrometers. Radiational heating and salt incrustation of the wet-bulb muslin almost certainly led to positive errors of unknown though probably small magnitude.

The errors inherent in sea-surface temperature measurements are transferred to calculations of the mean saturation vapor pressure of air at sea-surface temperature.

Using dew points, obtained from the coded weather messages, we computed vapor pressures (mb) by applying the empirical equation (Berry et al., 1945, p. 343):

$$e = 6.11 \times 10^{\frac{7.5t}{237.3 + t}}$$

where t = dew point in °C.

#### CLOUDS AND PRECIPITATION (CHARTS 97-120)

Total cloud amount is notoriously difficult to determine from shipboard and since it possesses a larger gradient than any other meteorological vari-

able, except perhaps precipitation, a single observation is unlikely to be representative. Even averaging reveals only gross features. Thus, we have added to these charts, two sets of isopleths obtained from weather satellites. The first set, available only for parts of the region in the months of May 1963, January through April 1964, June 1964, and December 1964, represents averages of total cloud cover obtained from nephanalyses of the original television pictures. The second, available for the period June 1963 through December 1964, depicts monthly means based on emitted radiation in the 8-12 micron atmospheric "window" as measured by the weather satellite TIROS VII. The analyses were made by Mr. L. J. Allison and Major E. R. Kreins, both of the Goddard Space Flight Center, Greenbelt, Maryland. They write (1967): "One of the channels of the radiometer responded to emitted radiation in the 8-12 micron portion of the electromagnetic spectrum where gaseous absorption in the atmosphere is minimal . . . The equivalent black body temperature measurements were averaged . . . over 5 degrees of longitude mesh (and smoothed) . . . (T)he calibration of the radiometer was observed to degrade while in orbit; (suitable) corrections were applied in the computer processing of these maps . . . Effective radiation height is that height in the atmosphere where the ambient air temperature equals the equivalent black body temperature . . . (T)hin cirrus clouds act as if they are partially transparent and permit the warmer radiation from below to be recorded by the TIROS radiometer . . . When a homogeneous overcast cloud layer or clear skies . . . fill the field of view of the radiometer, a uniform interpretation of the equivalent black body temperatures . . . can be made. But if scattered or broken cloud decks of varying transparency are viewed, the radiation originating from the ground and the various cloud layers contributes to the integrated intensity detected by the satellite." See also, Allison and Warnecke, (1966) and Winston, (1969).

By judiciously comparing averages of spot observations with the two sets of averages of areal observations of clouds, an investigator can learn much about the character as well as the amounts of clouds. Over cloudless areas, the equivalent black-body temperatures—by revealing the patterns of sea-surface temperatures—could add useful detail to the analyses on Charts 49-72.

Because of the nature of the phenomena, frequencies of observations reporting precipitation or thunderstorm manifestations have little meaning in the samples of fewer than ten observations. Even with long-period records, the variations of precipitation frequency distributions among meteorological atlases is remarkable. Not surprisingly, where average cloudiness exceeded 5/8, precipitation occurred most frequently.

#### HEAT EXCHANGE AT THE SEA SURFACE (CHARTS 121-144)

Many investigators have tried to derive empirical equations relating the elements of standard marine meteorological observations to the heat budget at the ocean's surface. All the equations suffer from lack of accurate direct measurements of the budget components, in particular, during periods of strong winds and high seas. The equations used for this volume are based chiefly on the work of Budyko (1956) and Roden (1959). Although the patterns of heat exchange derived from the equations are probably realistic,



absolute values and magnitude of gradients qualify only as approximations (Garstang, 1965).

In the heat balance equation:

$$Q_{st} = Q_s - Q_r - Q_b - Q_e - Q_h \quad (1)$$

where

$$Q_s = Q_0 (1 - \bar{C}k) \quad (2)$$

$$Q_r = (Q_s \times k') \quad (3)$$

$$Q_b = S\sigma T_s^4 (0.39 - 0.050 \sqrt{e_a}) (1 - k'' \bar{C}^2) + 4S\sigma T_s^3 (T_s - T_a) \quad (4)$$

$$Q_e = 5.17 (e_s - e_a) u \text{ where } e_s > e_a \quad (5a)$$

$$Q_e = 7.7 \times 10^{-5} (444 - 0.56 T_s) (0.98 e_s - e_a) u \quad (5b)$$

where  $e_s < e_a$

$$Q_h = Q_e 0.66 \left( \frac{T_s - T_a}{e_s - e_a} \right) \quad (6)$$

Symbols:

- $Q_{st}$  Net heat balance at the sea surface in  $\text{cal cm}^{-2} \text{ day}^{-1}$ .
- $Q_s$  Rate of heating at the sea surface from incoming shortwave radiation, modified by the total average cloud cover.
- $Q_r$  Rate at which radiation is reflected from the sea surface.
- $Q_b$  Rate of emission of back radiation from the sea surface.
- $Q_e$  Rate of cooling at the sea surface from evaporation.
- $Q_h$  Rate of sensible heat loss from the sea surface to the atmosphere.
- $Q_0$  Rate of heating at the sea surface from incoming shortwave radiation under clear skies.
- $\bar{C}$  Average total cloud cover in tenths.
- $k$  Correction factor for cloud cover from Roden (1959).
- $k'$  Empirical factor from Roden (1959) based on average cloud cover and sun's altitude for selected latitudes.
- $S$  Emissivity of the sea  $\approx .98$ .
- $\sigma$  Stefan-Boltzmann constant.
- $\left. \begin{matrix} T_s \\ T_a \end{matrix} \right\}$  Temperatures of sea surface and air (at 10 m) in deg K.
- $e_a$  Vapor pressure of air at 10 m in mb.
- $e_s$  Saturation vapor pressure at the sea-surface temperature.
- $k''$  Empirical factor from Roden (1959) which is a function of latitude and the climatological vertical extent of cloud cover.
- $u$  Wind speed in  $\text{m sec}^{-1}$ .

The amount of solar radiation reaching the sea surface depends on the season and cloudiness, whereas the amount of heat abstracted from the sea by the air is directly related to the wind speed and air-sea temperature differences, in the case of sensible heat, and to the wind speed and the vertical vapor pressure gradient in the case of latent heat. Hence, the net heat balance at the sea surface integrates a complex set of effects. On the charts, the mean net radiation gain equals  $Q_s - Q_r - Q_b$ , while the mean equivalent heat loss equals  $Q_e + Q_h$ . The net heat balance at the ocean surface can therefore readily be obtained for each 5-degree square by sub-

tracting the sum of the latent heat and sensible heat losses from the net radiation gain.

The exchange terms were computed from the 5-degree square centered averages of the observed variables.

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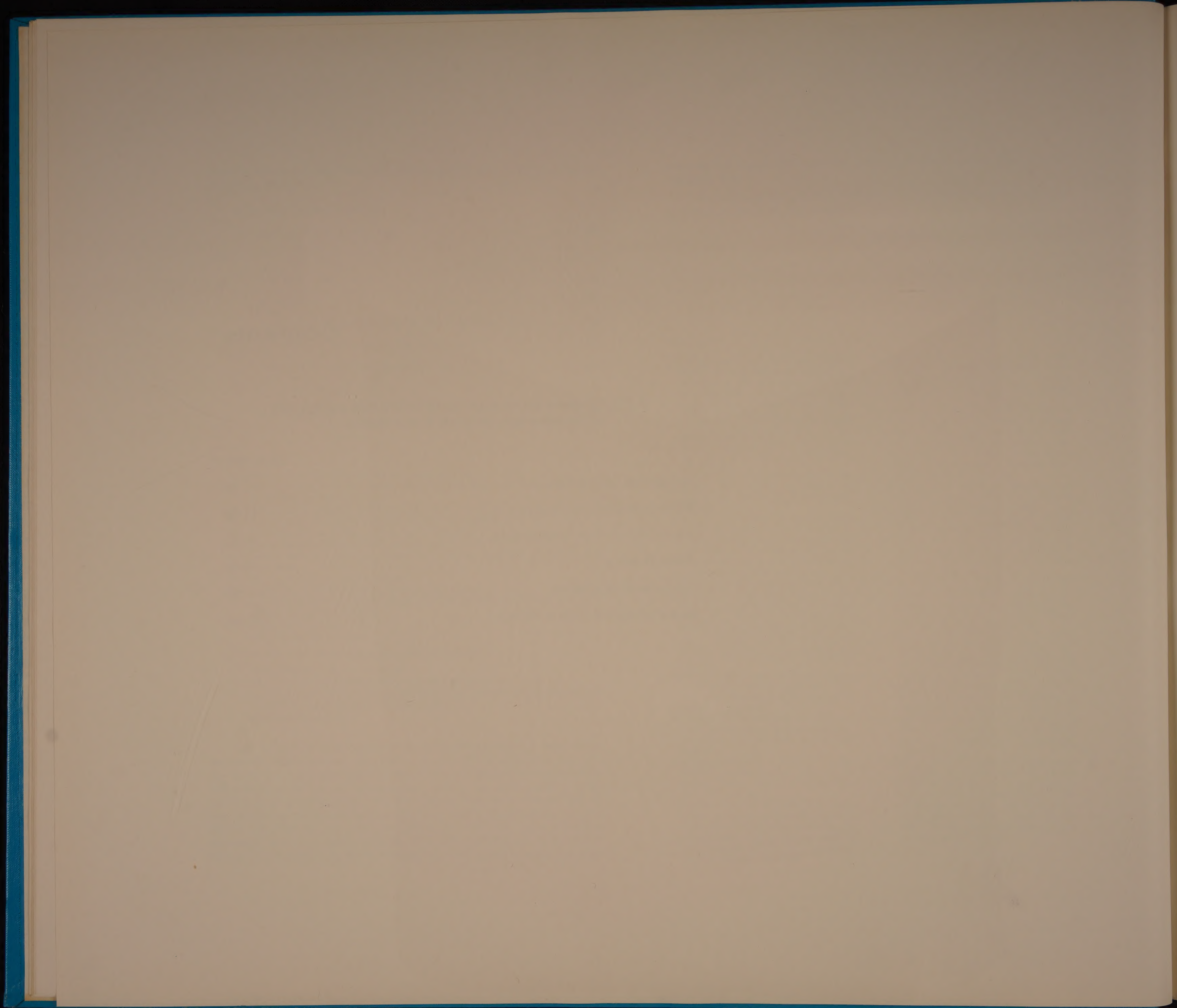


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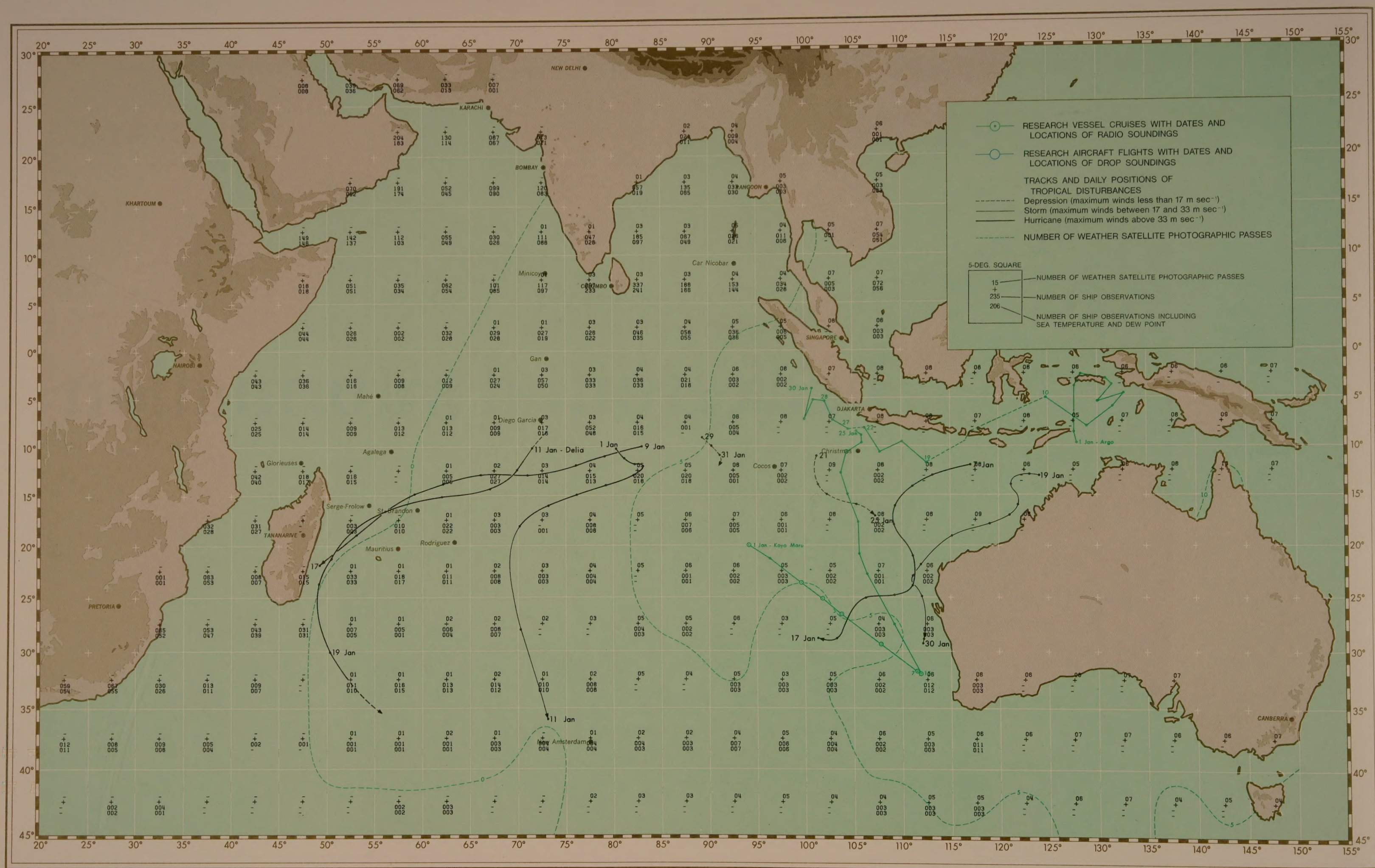




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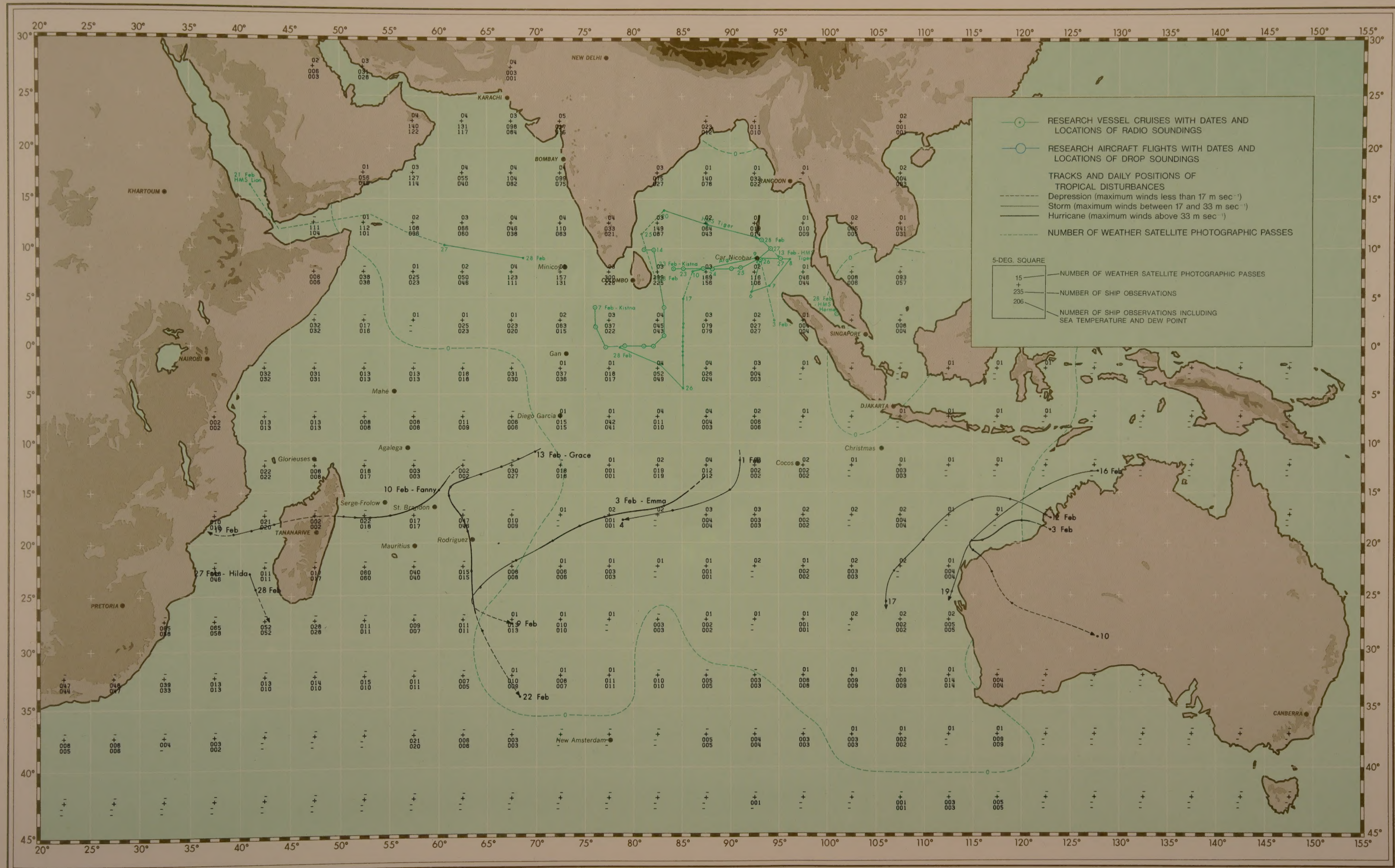


# BACKGROUND INFORMATION January 1963 Chart 1





# BACKGROUND INFORMATION February 1963 Chart 2



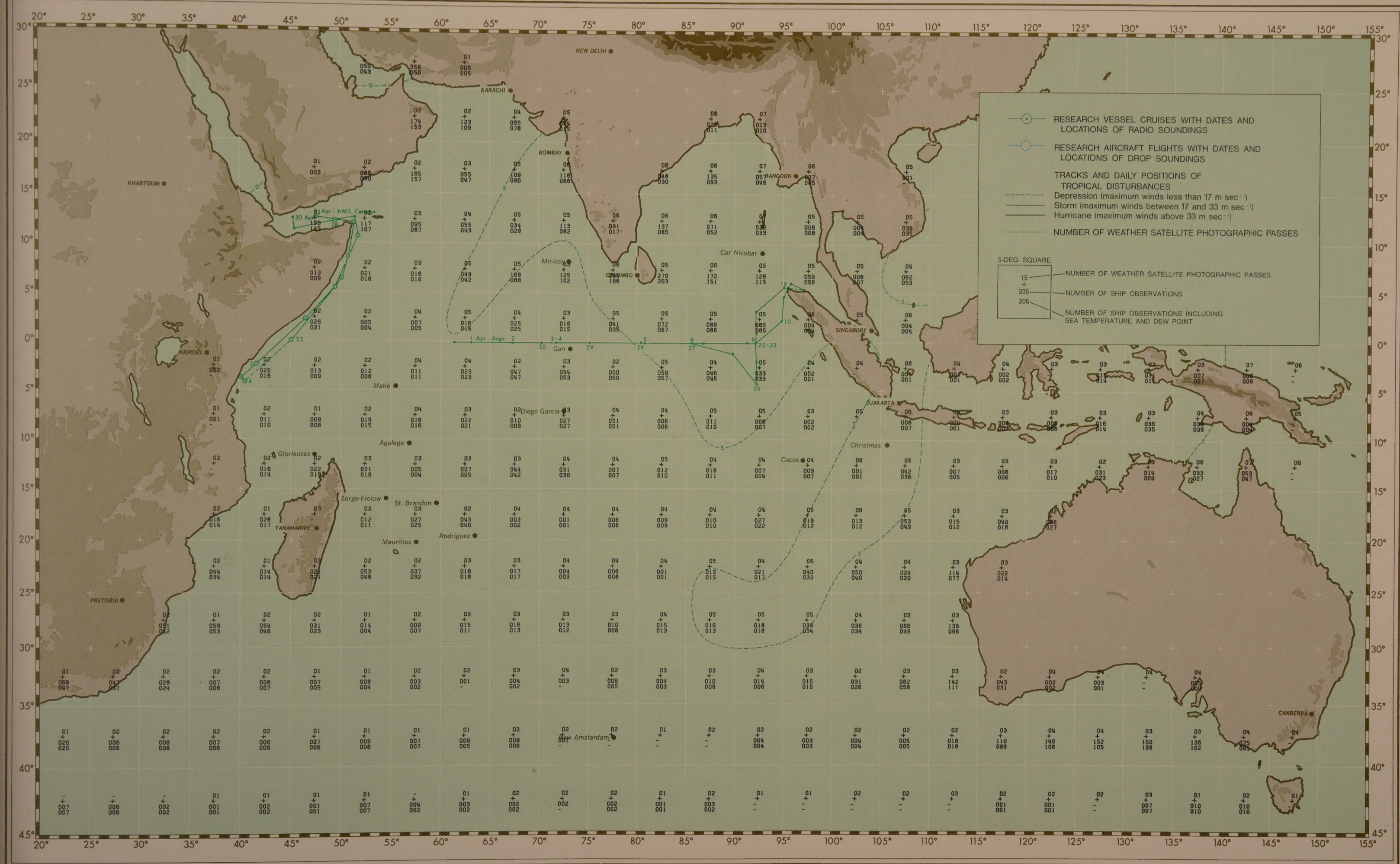


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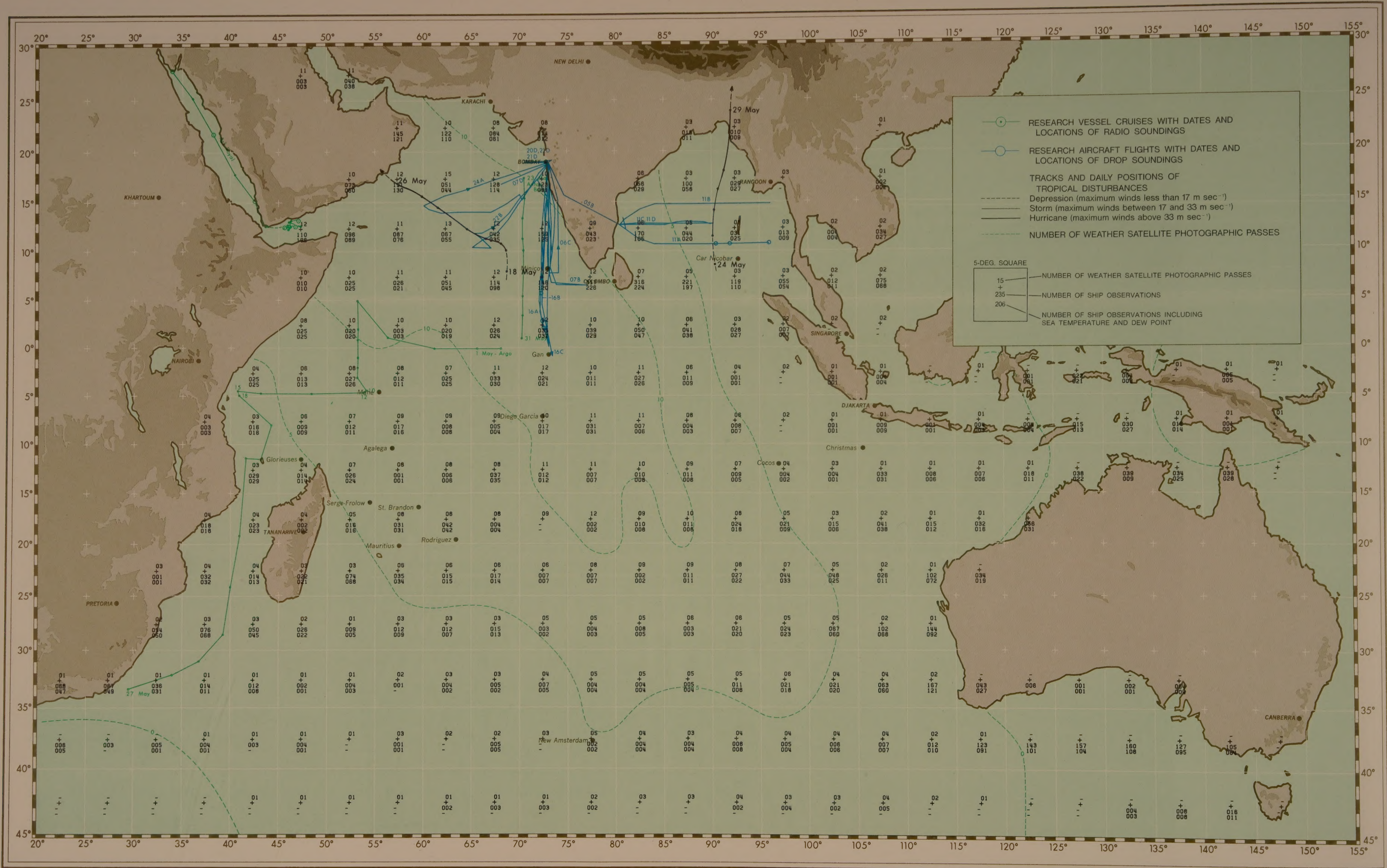


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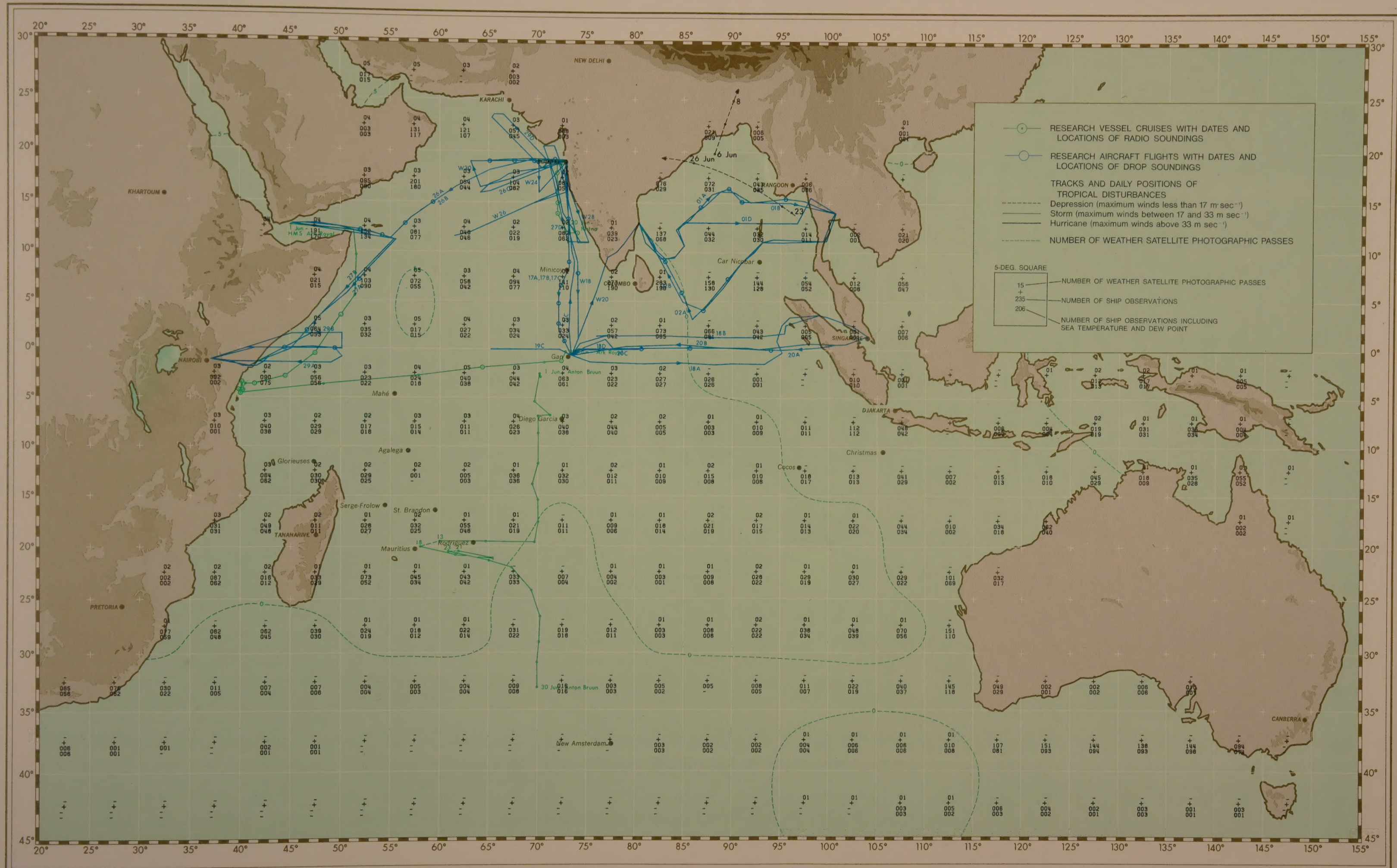


**BACKGROUND INFORMATION**    May 1963    Chart 5





# BACKGROUND INFORMATION June 1963 Chart 6

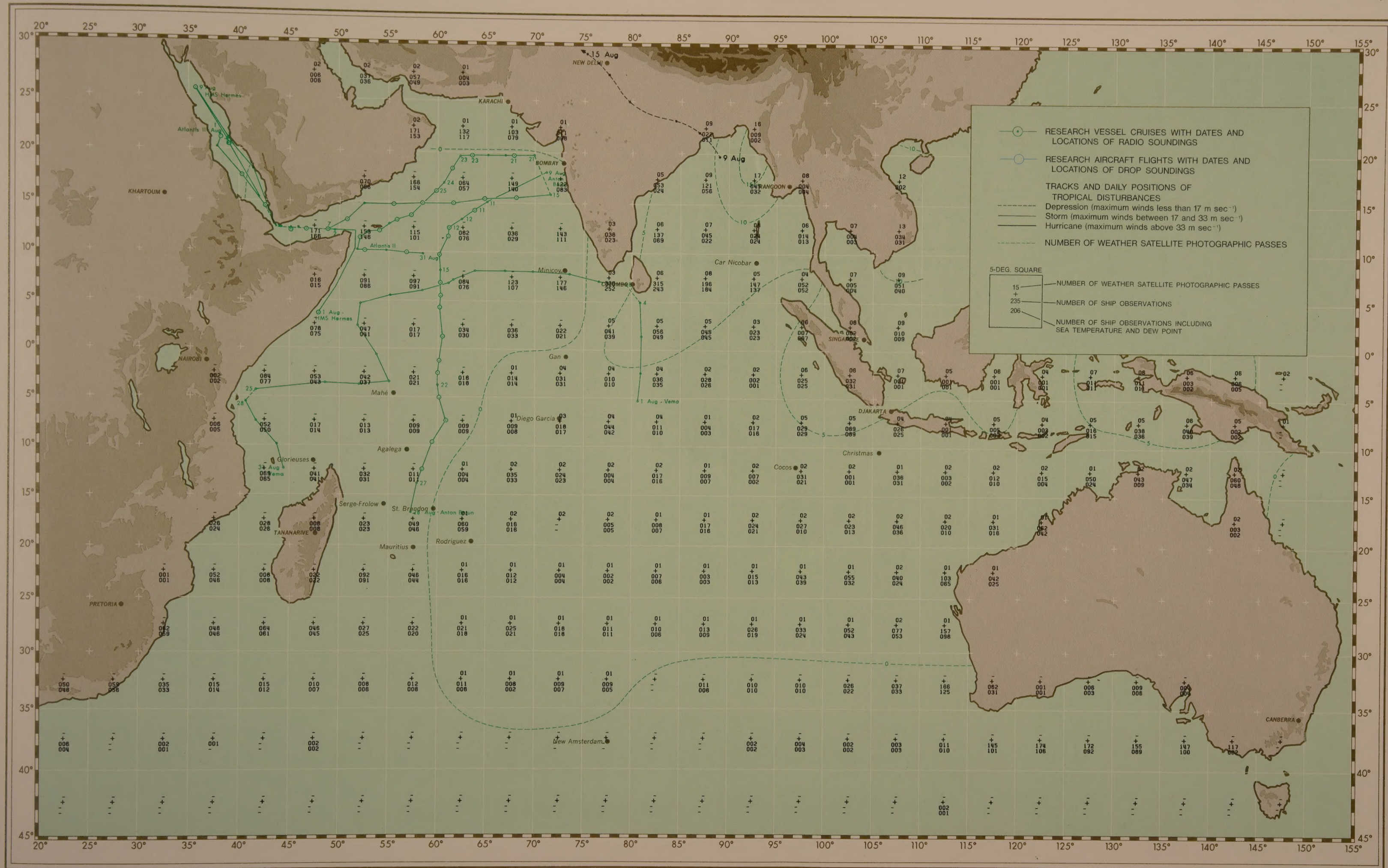




**BACKGROUND INFORMATION**    July 1963    Chart 7

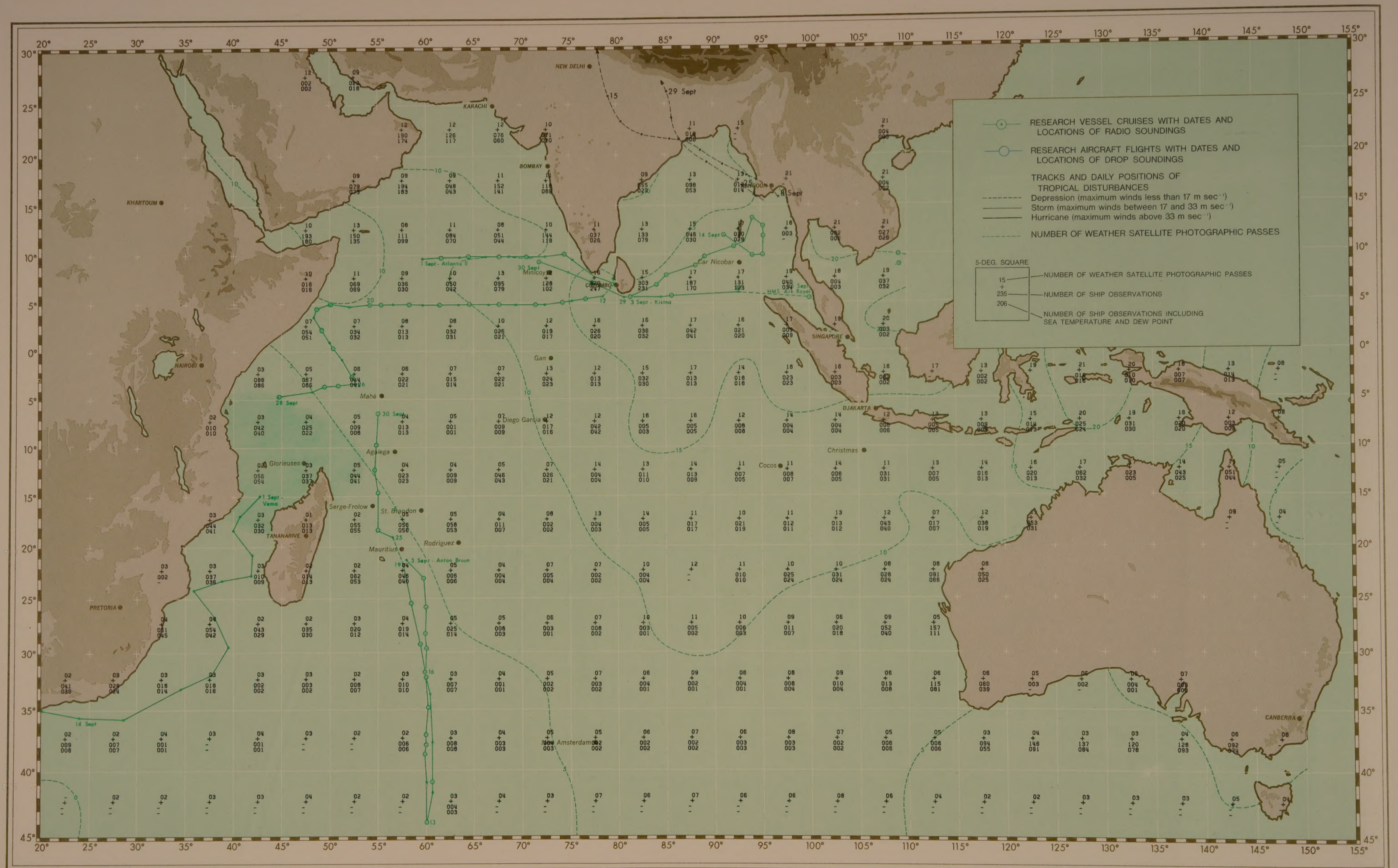


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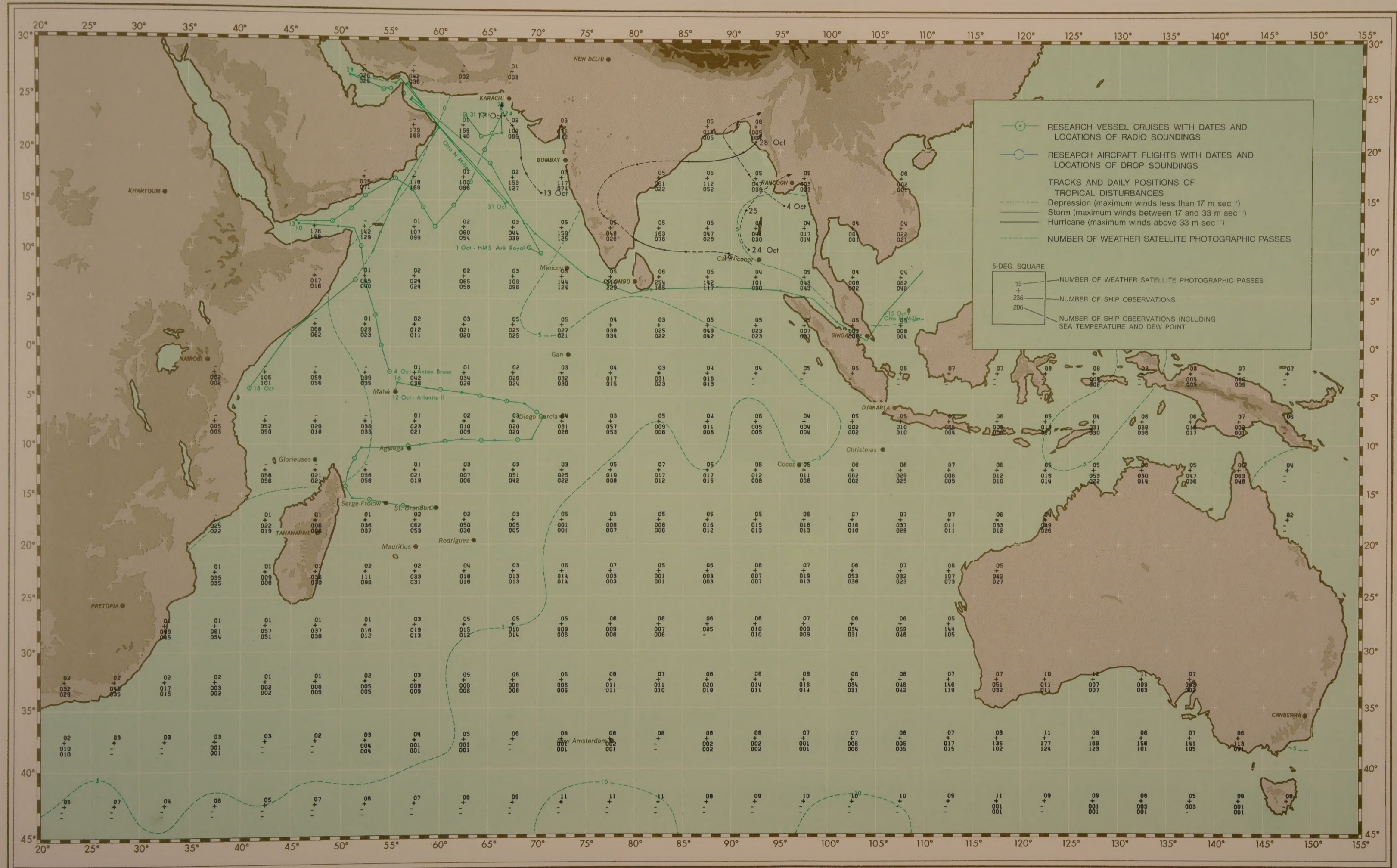


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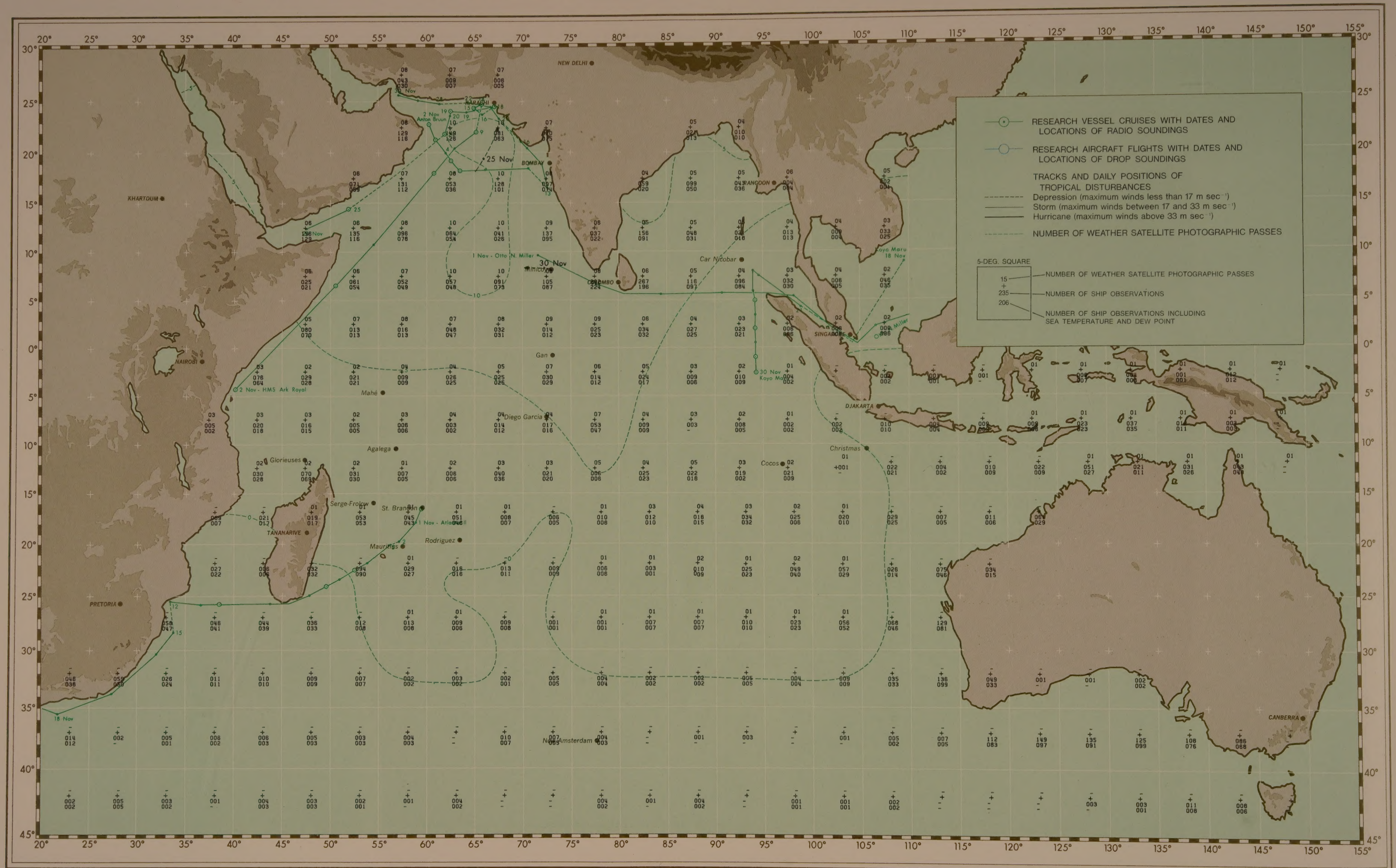


# BACKGROUND INFORMATION    October 1963    Chart 10



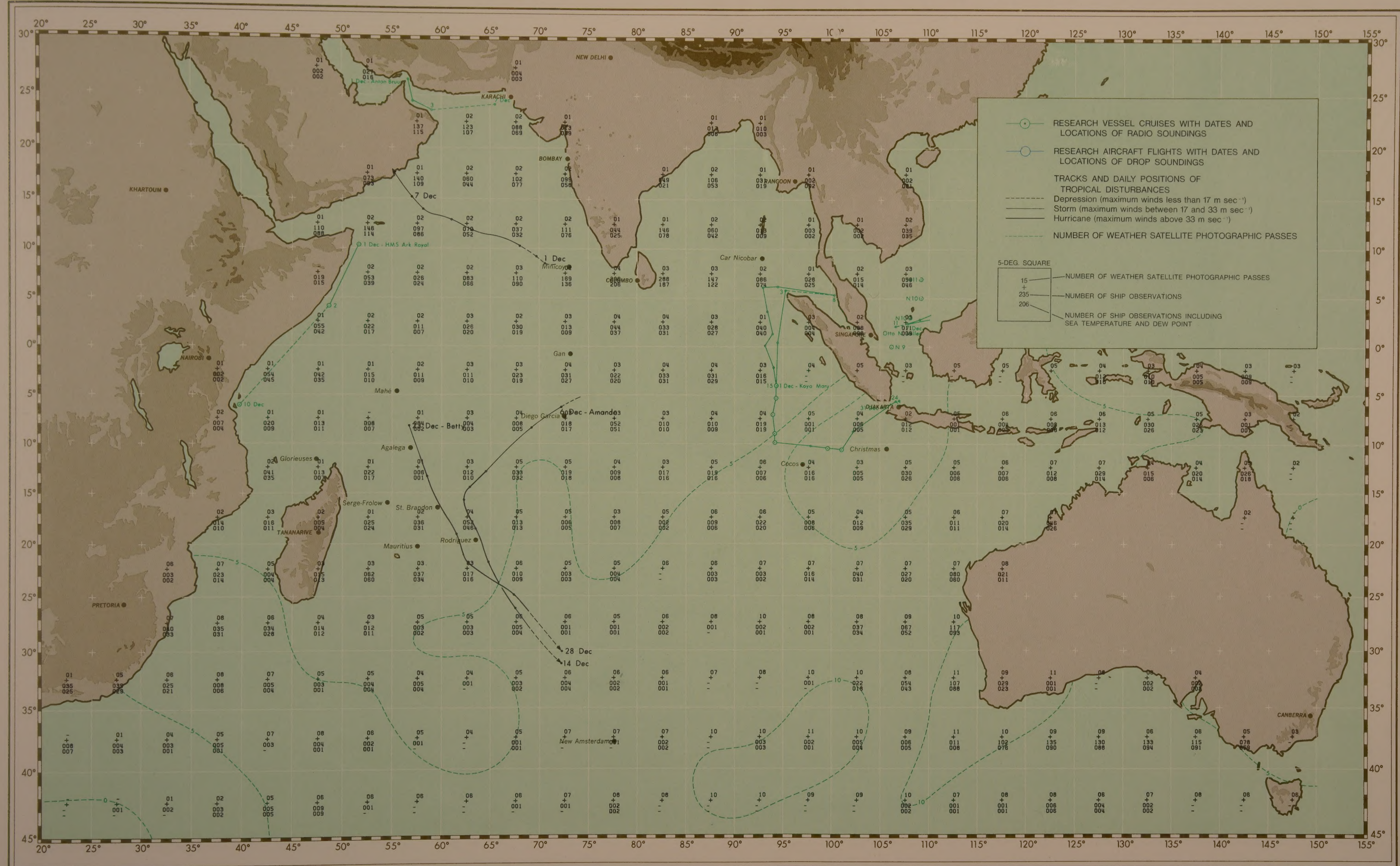


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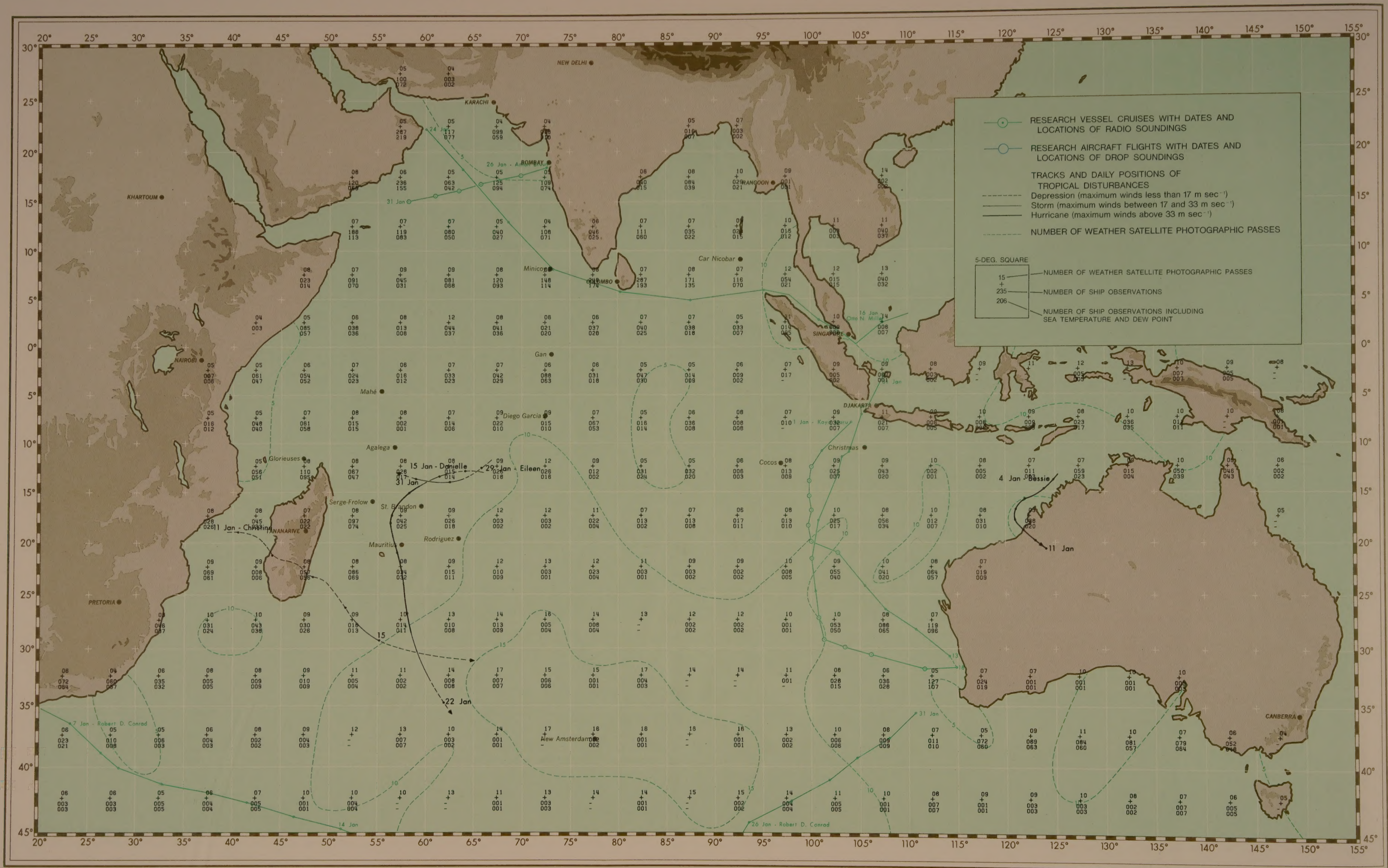


# BACKGROUND INFORMATION    December 1963    Chart 12





# BACKGROUND INFORMATION    January 1964    Chart 13

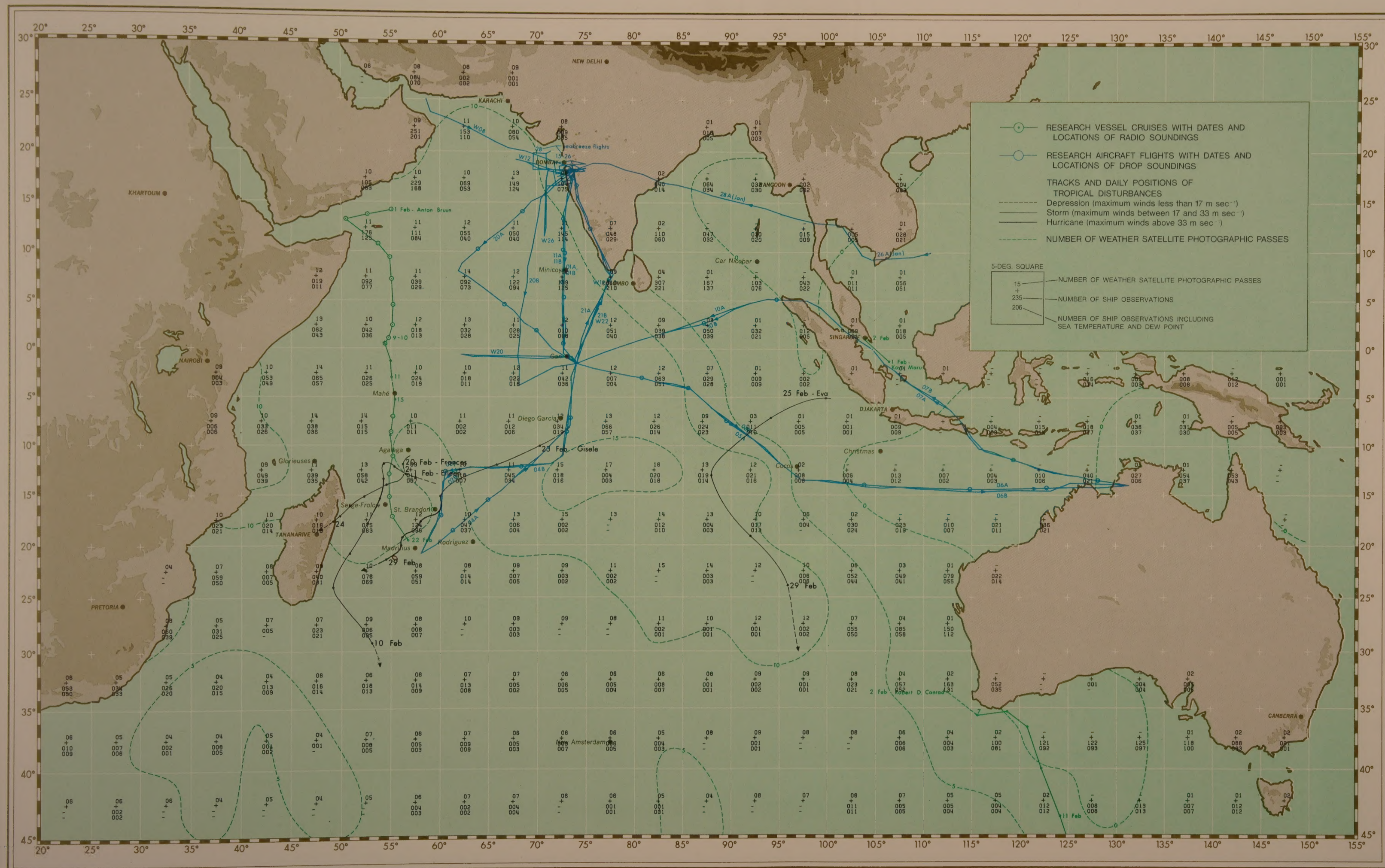




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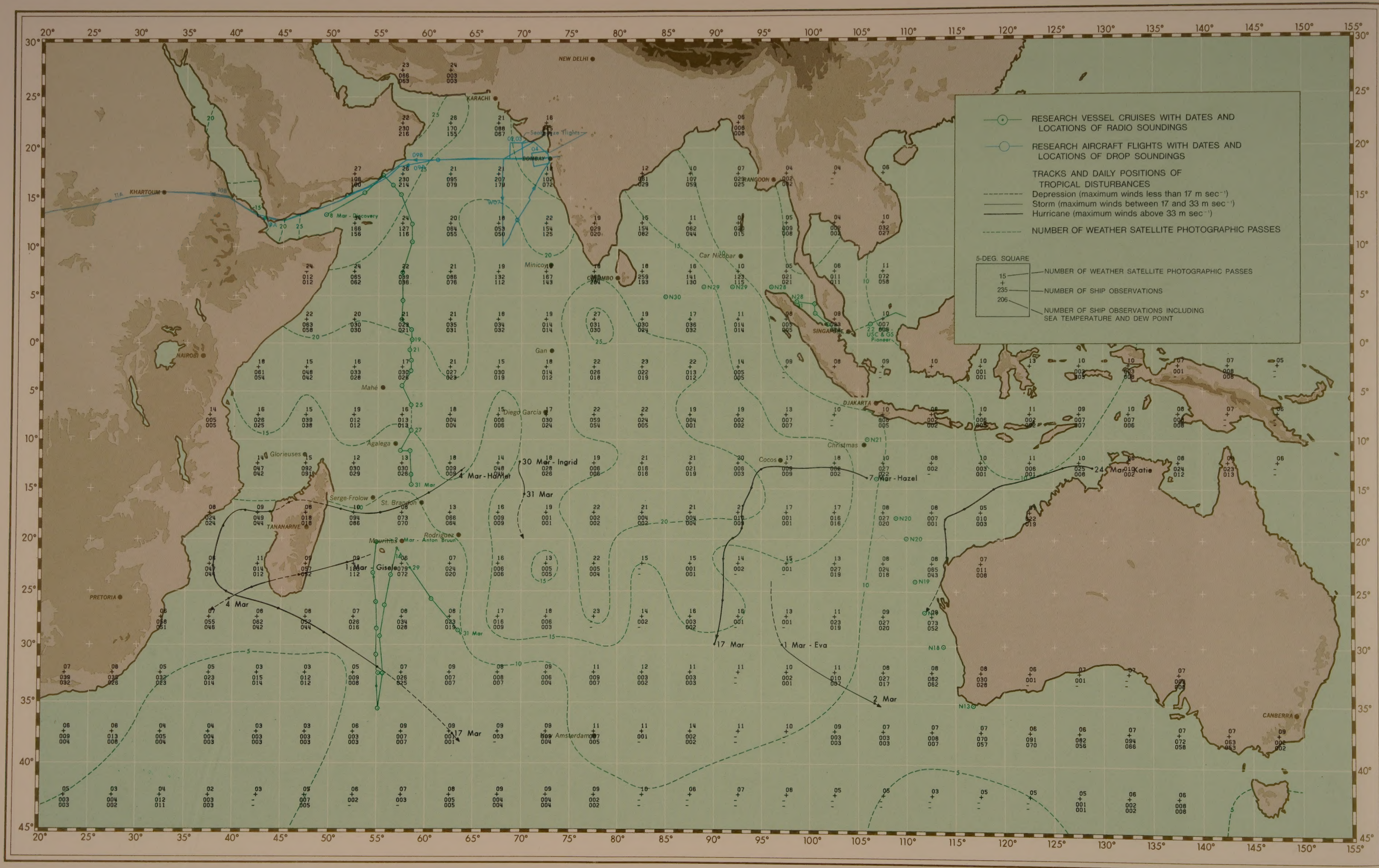
## February 1964

### Chart 14



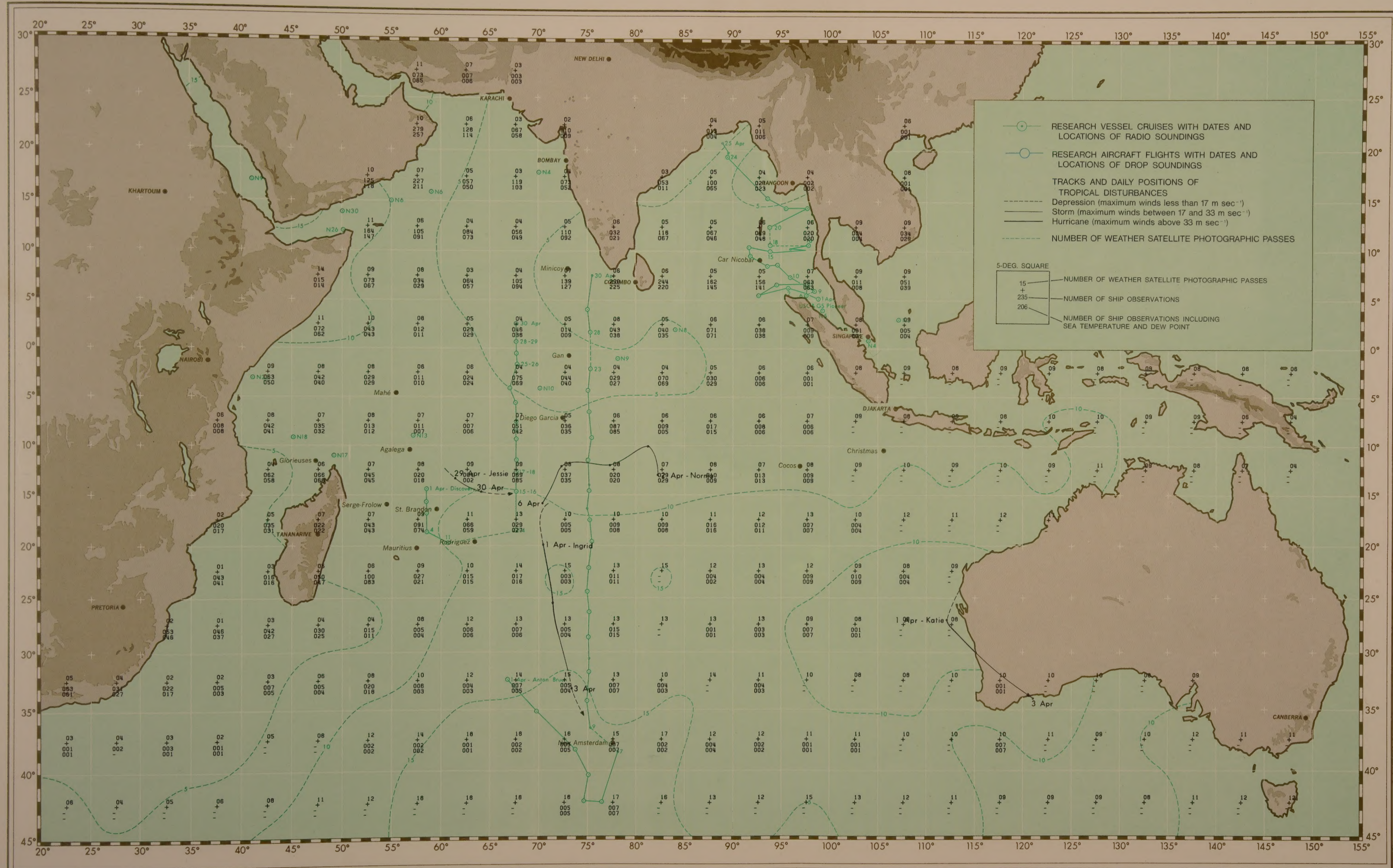


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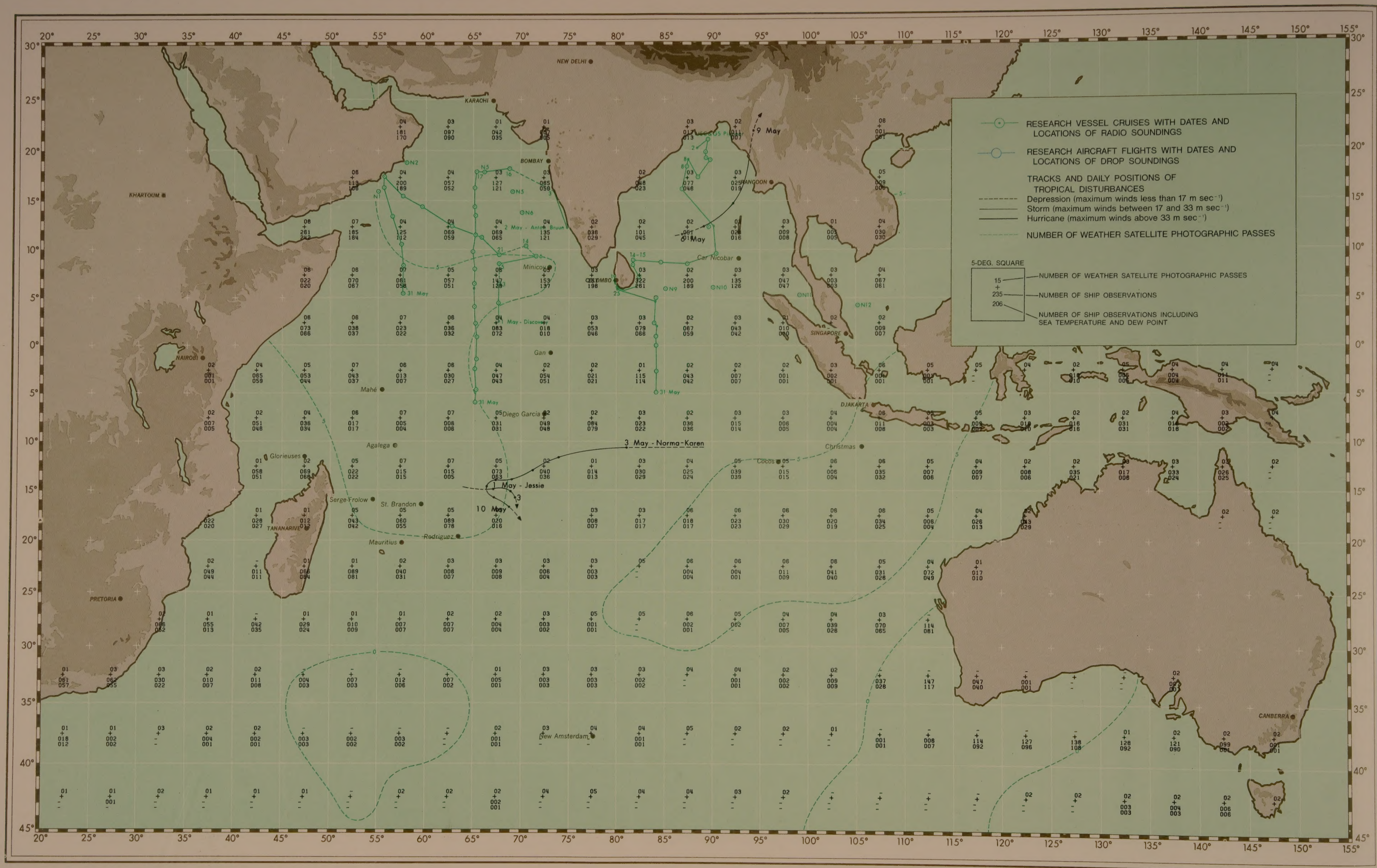


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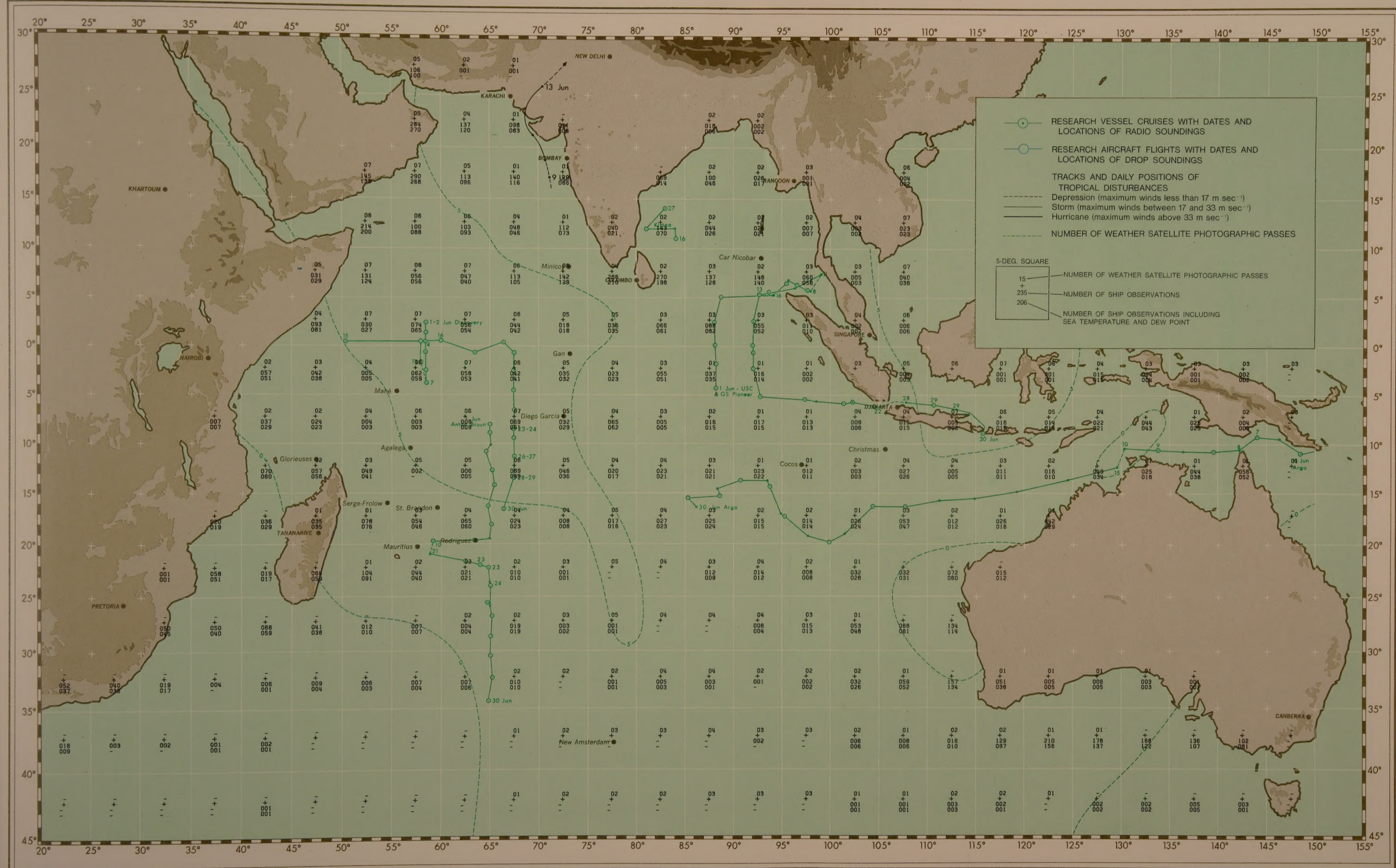


**BACKGROUND INFORMATION**    **May 1964**    **Chart 17**



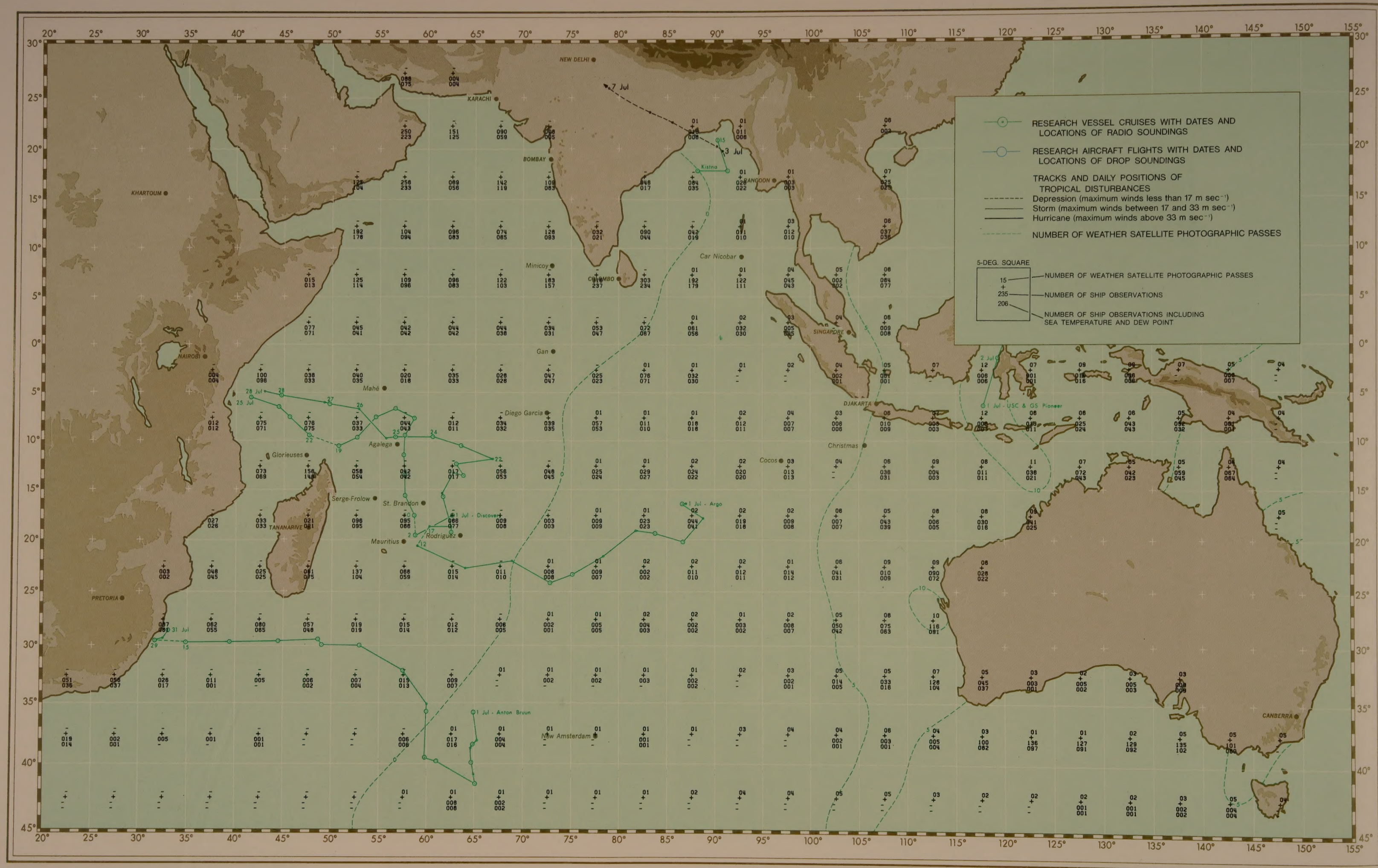


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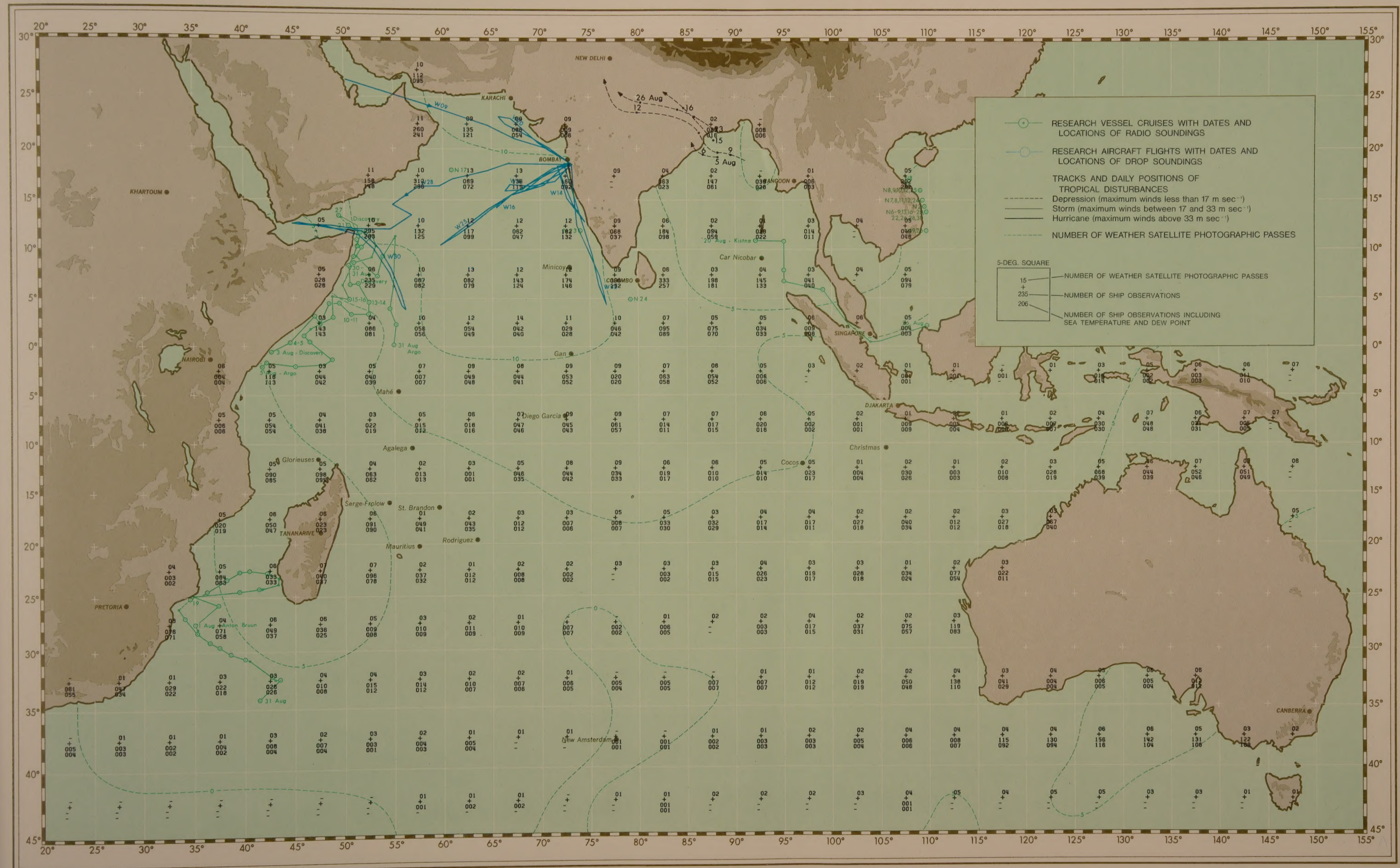


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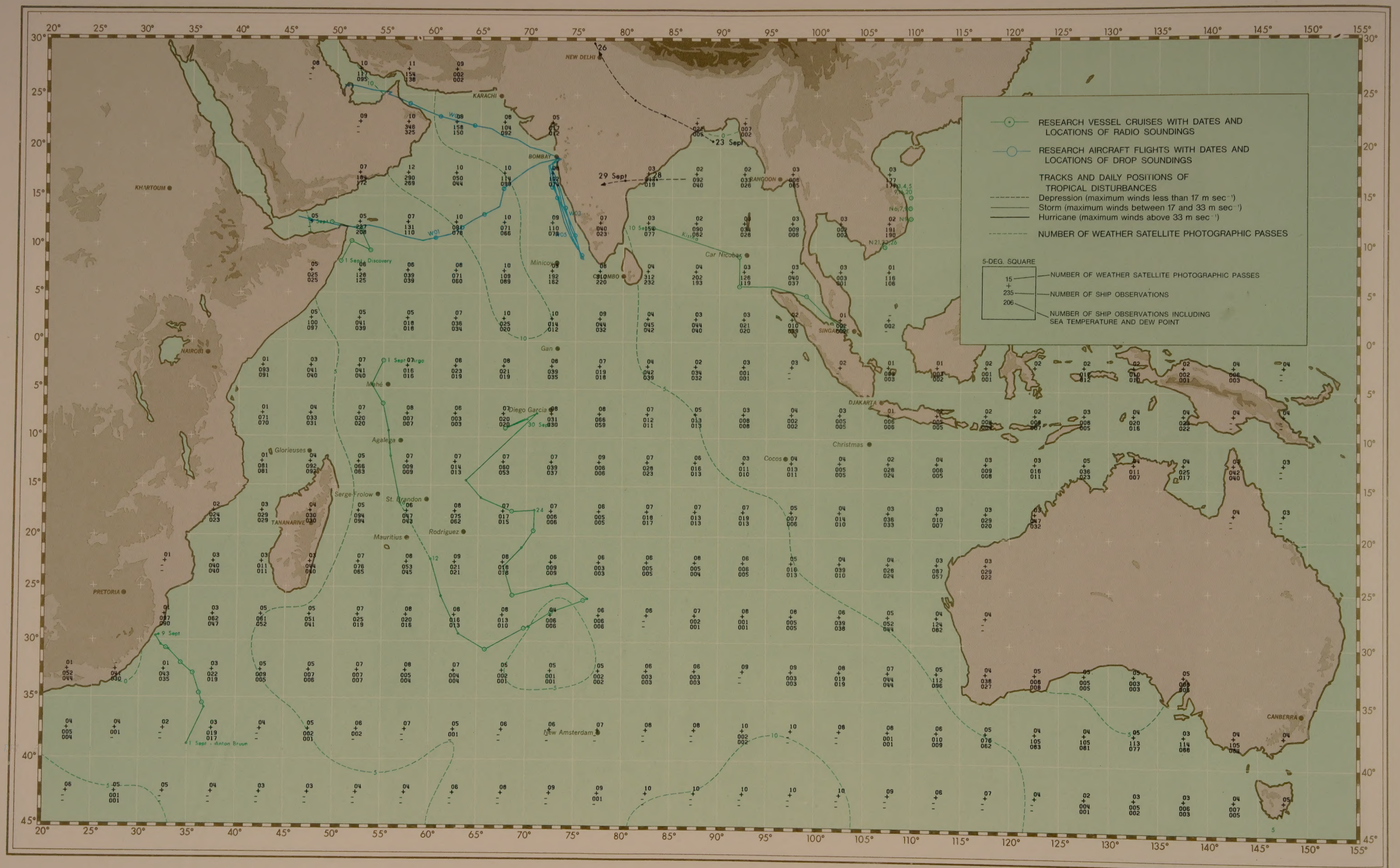


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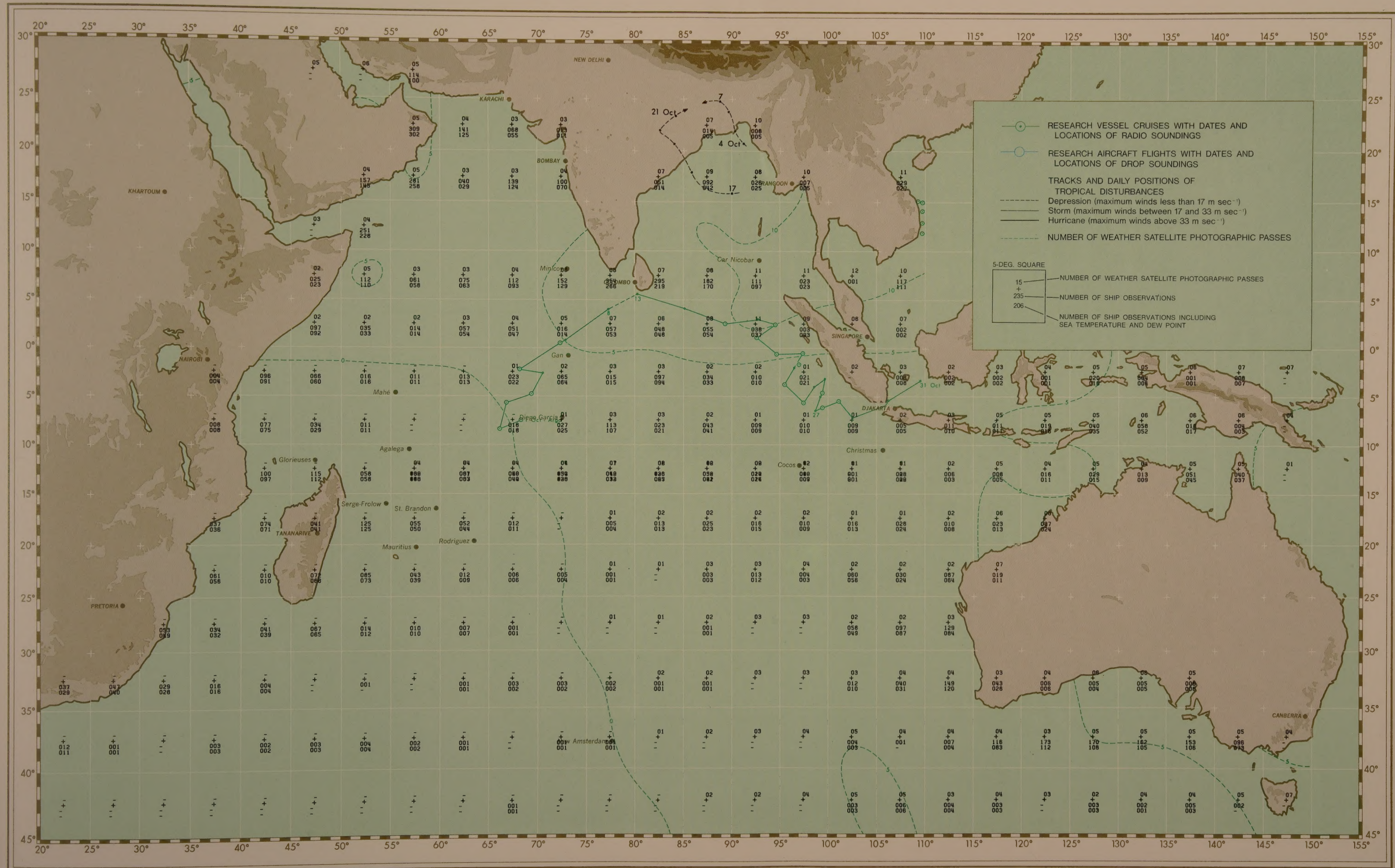


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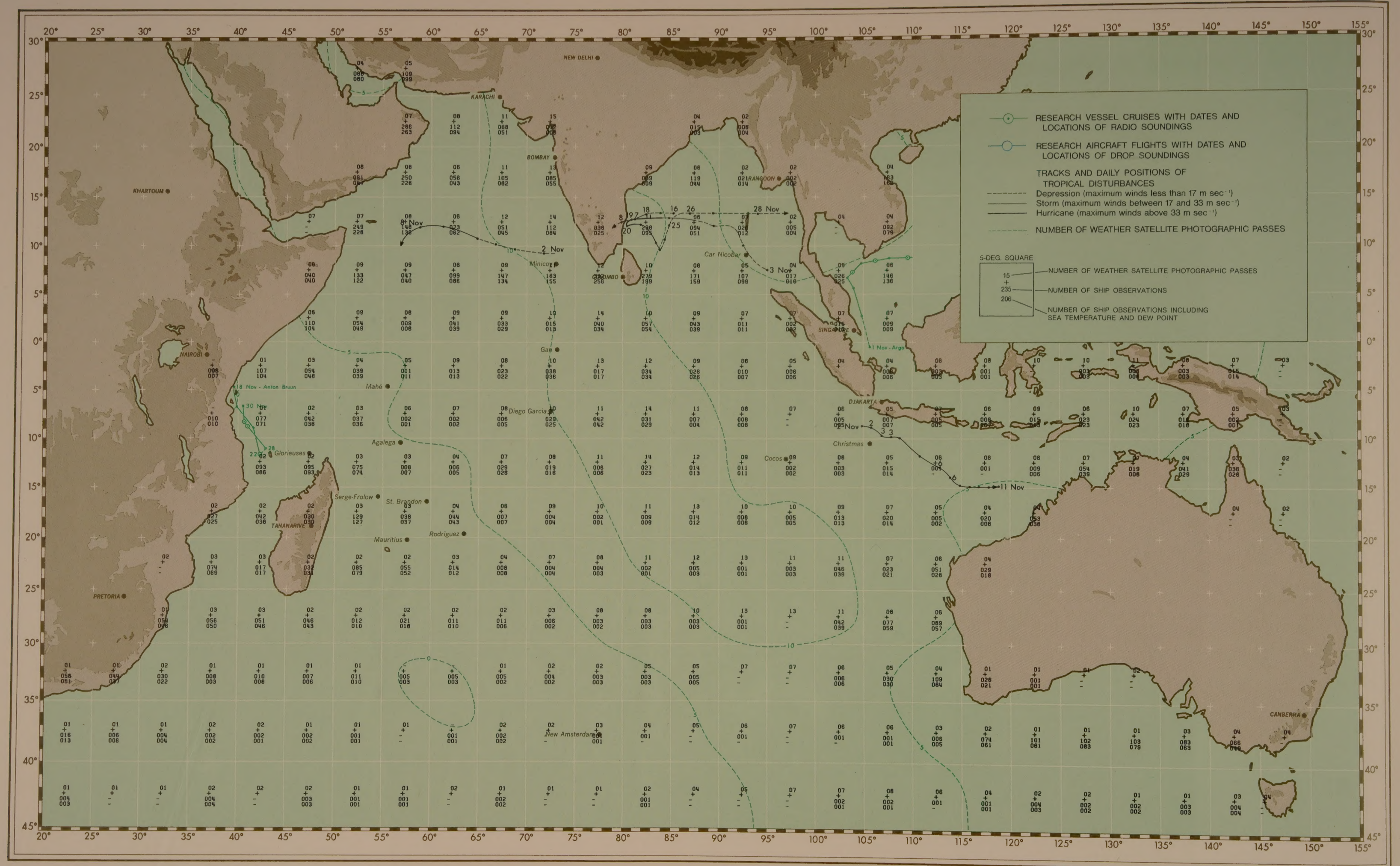


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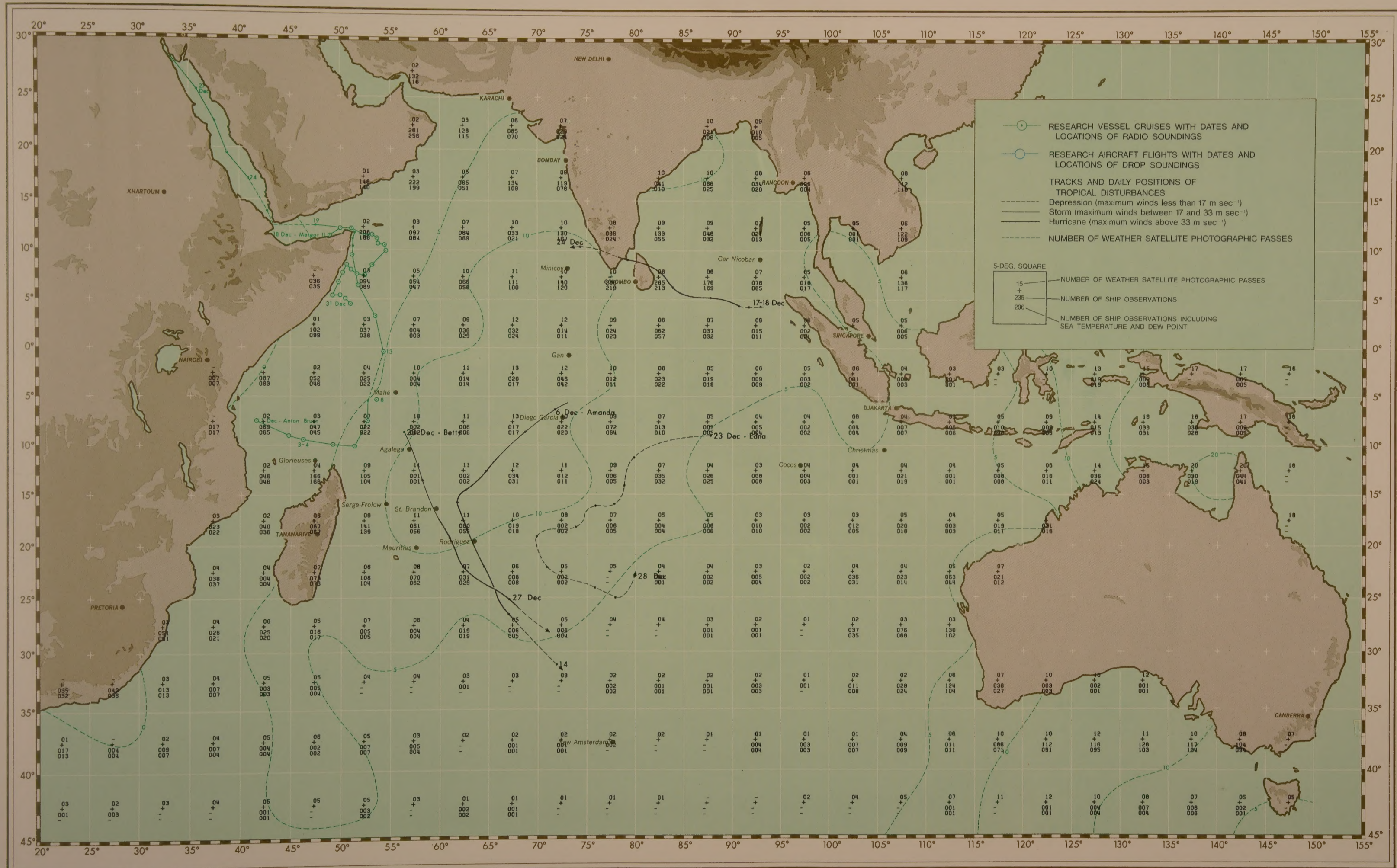


# BACKGROUND INFORMATION November 1964 Chart 23





# BACKGROUND INFORMATION      December 1964      Chart 24





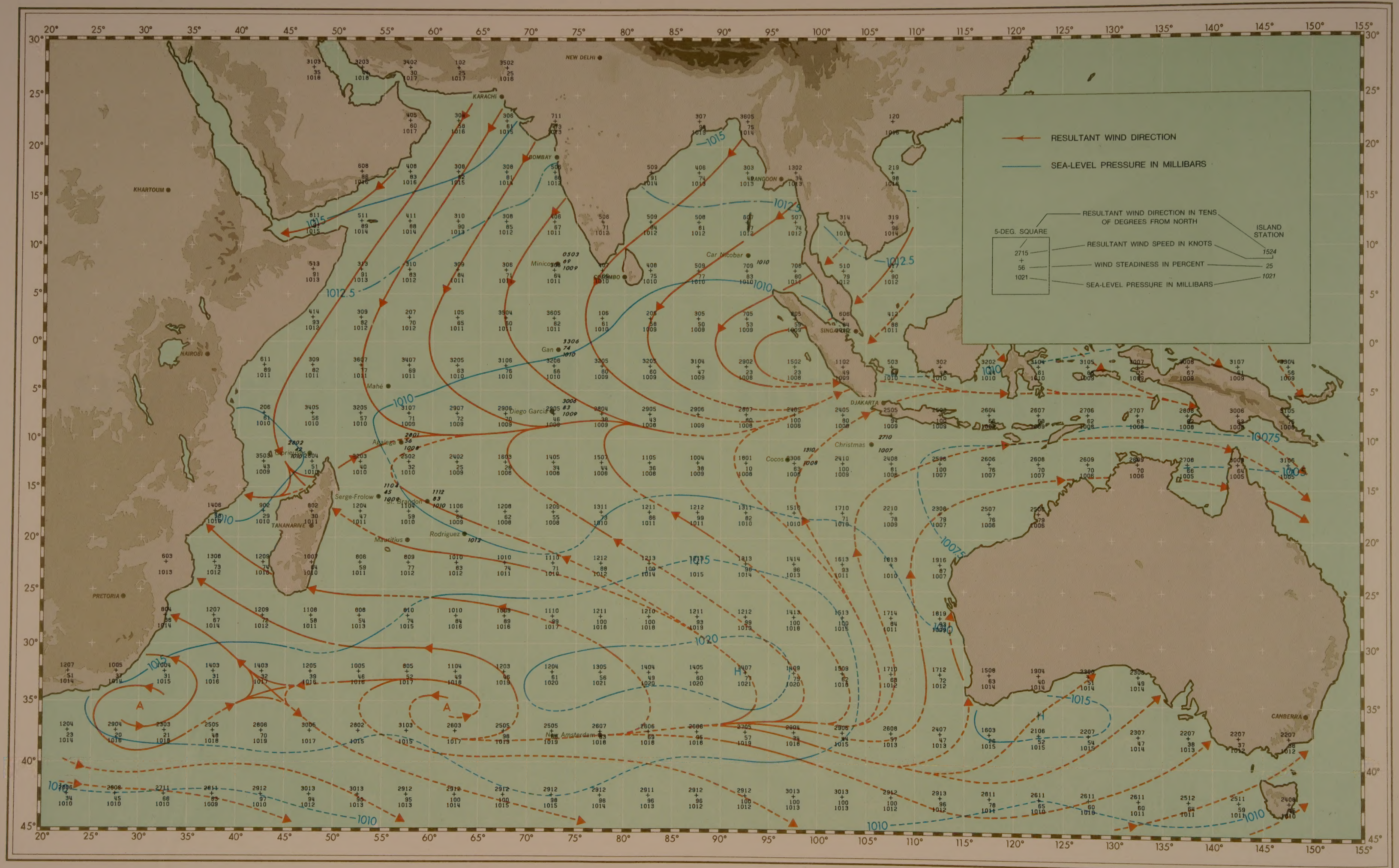




# Winds and Sea Level Pressure

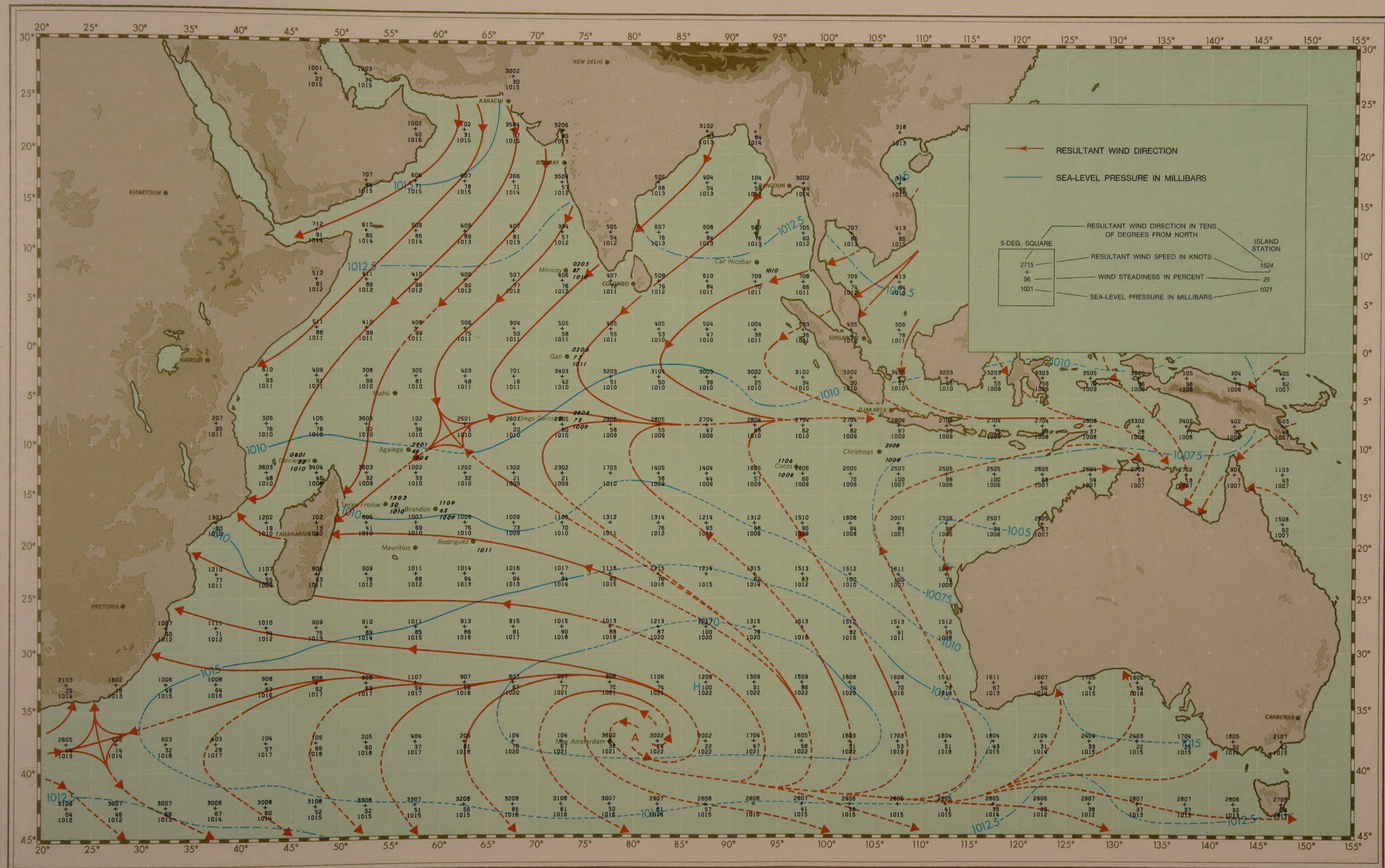


# WINDS AND SEA LEVEL PRESSURE January 1963 Chart 25



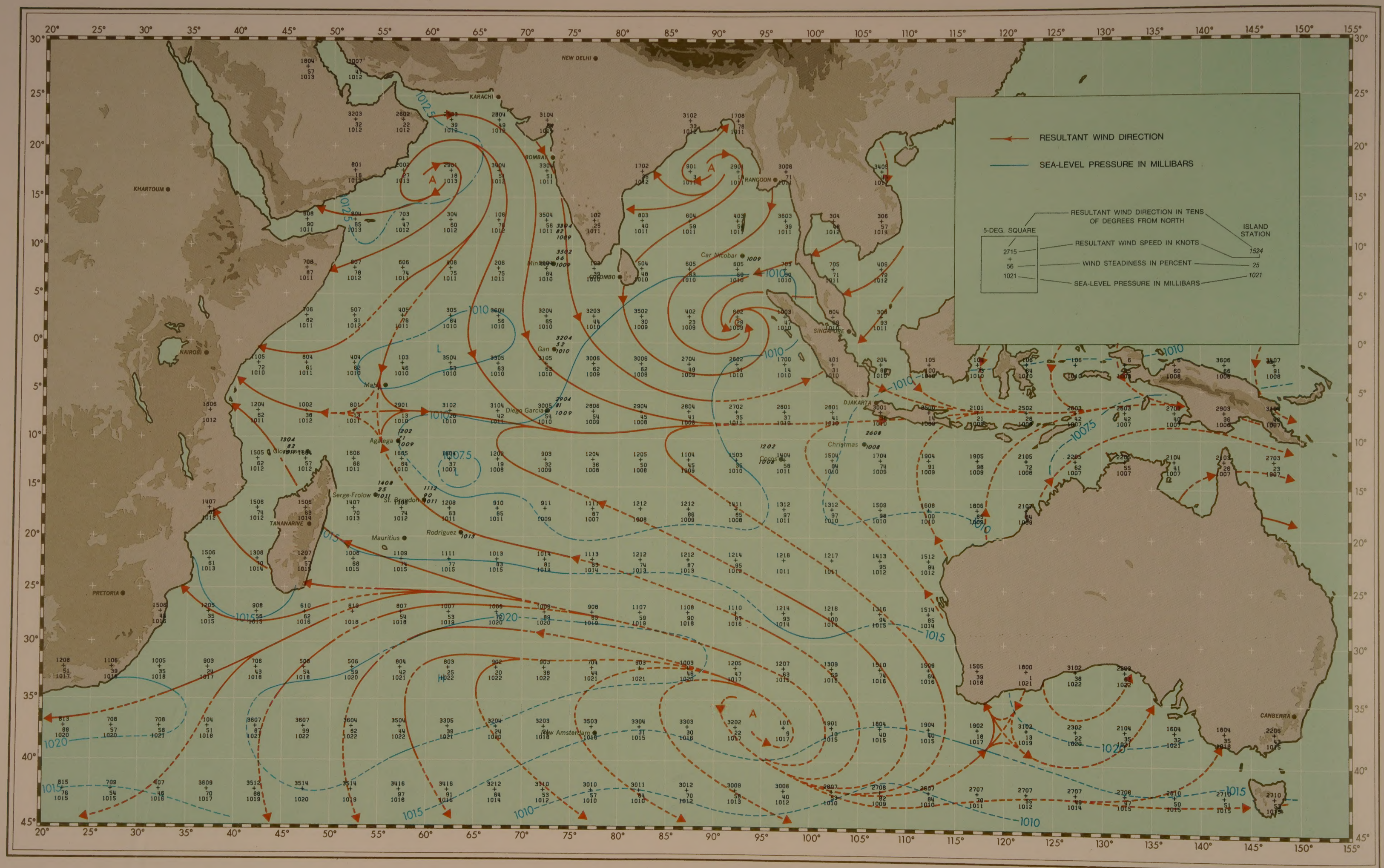


### Chart 26



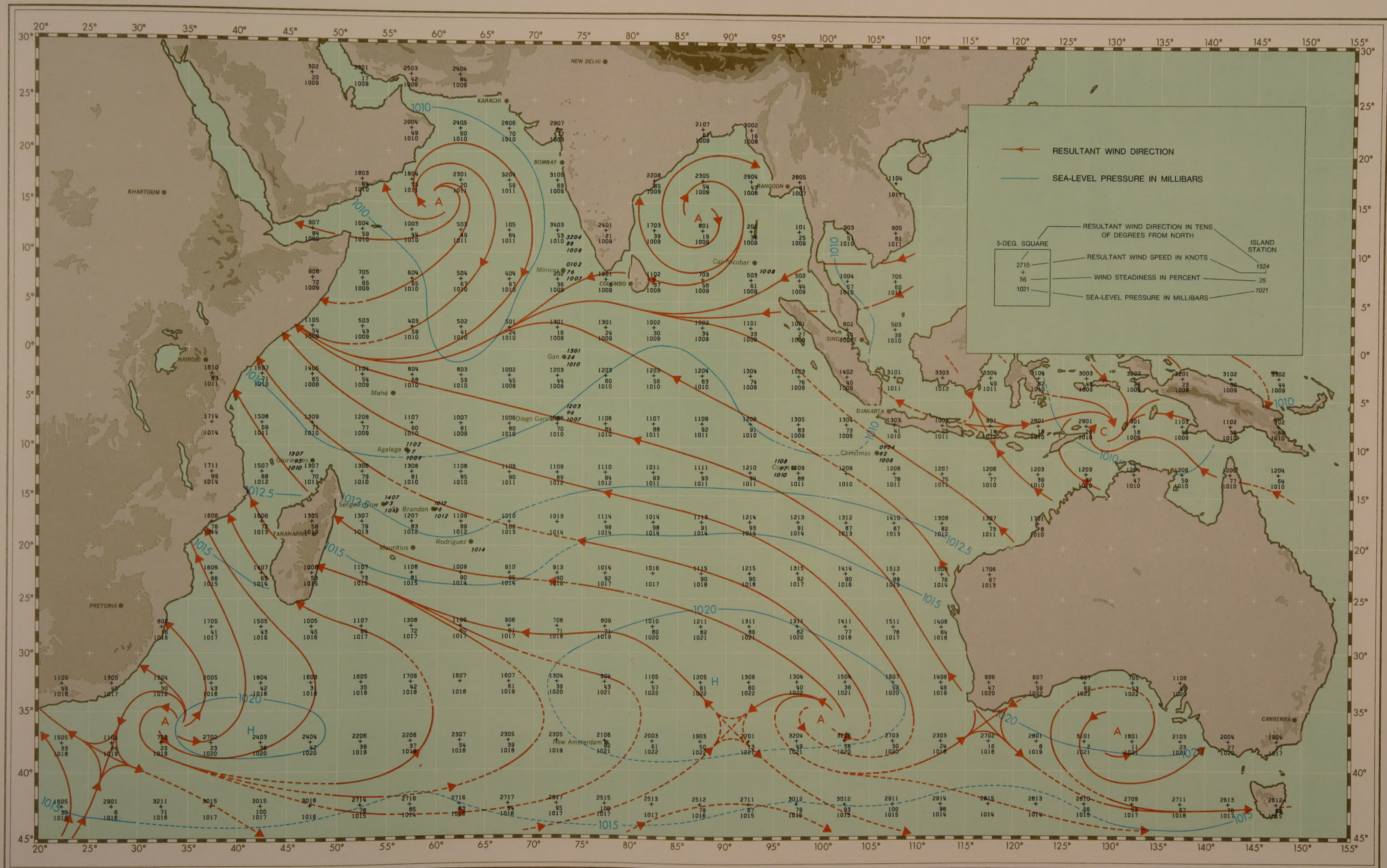


# WINDS AND SEA LEVEL PRESSURE March 1963 Chart 27



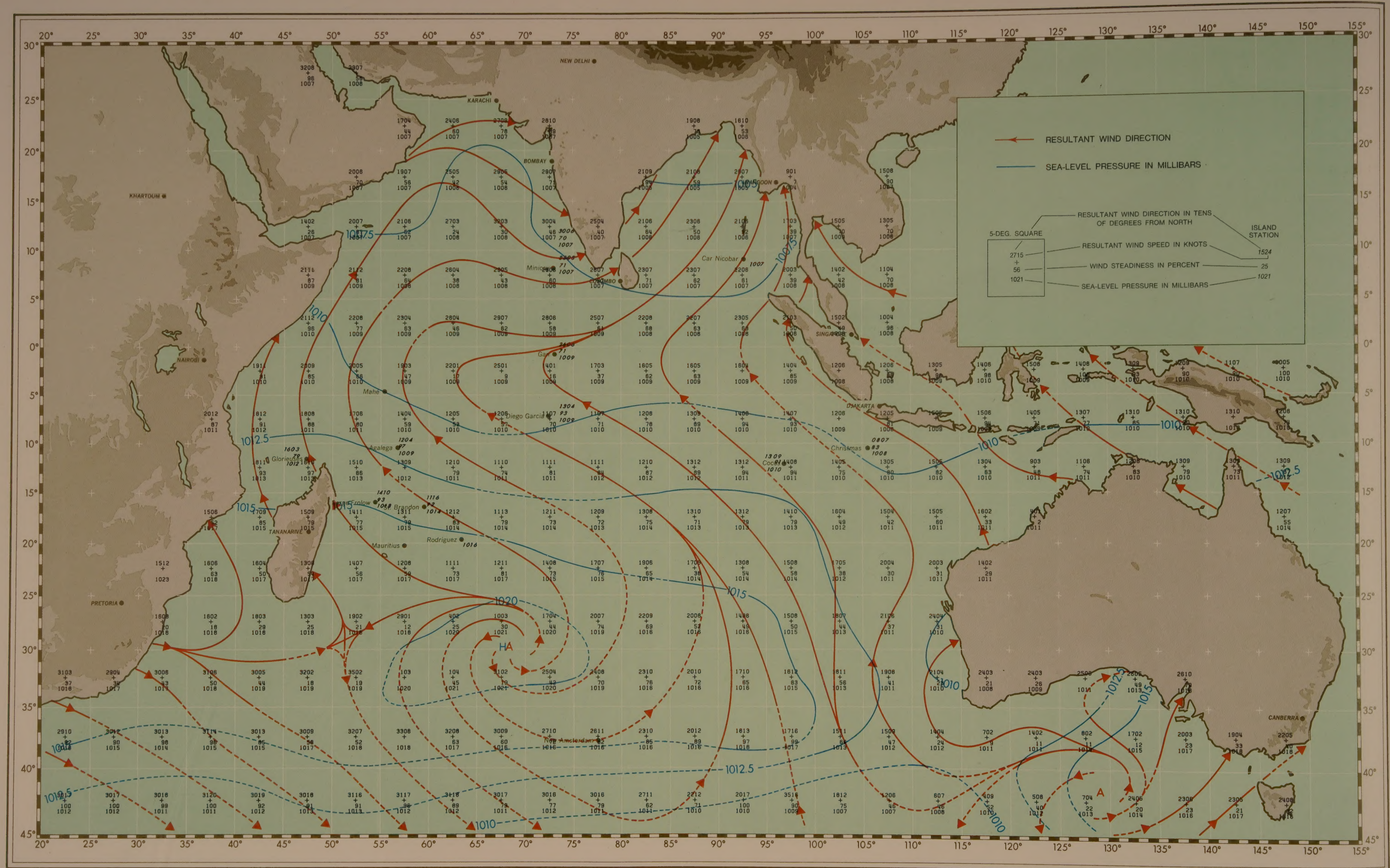


# WINDS AND SEA LEVEL PRESSURE April 1963 Chart 28



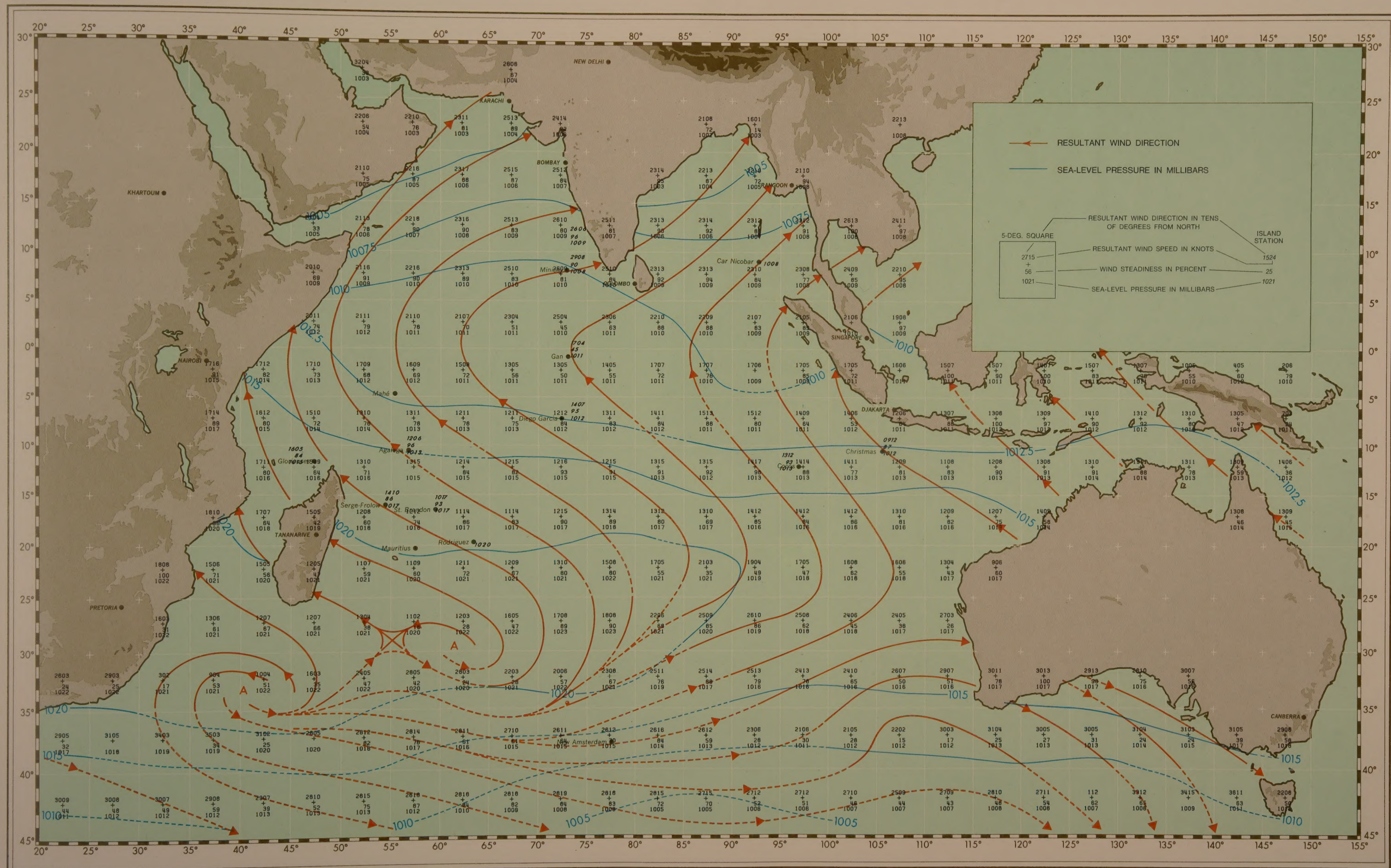


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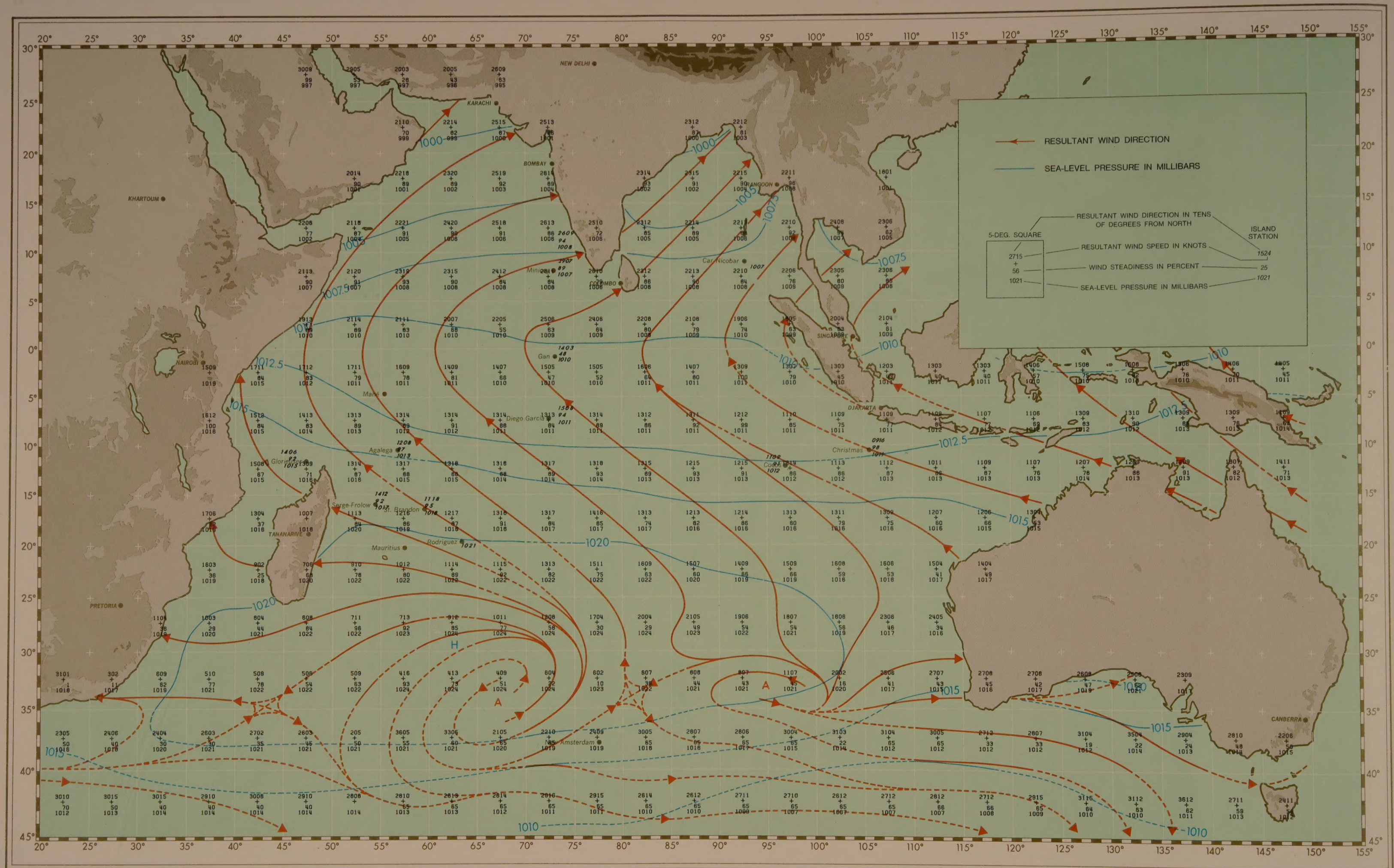


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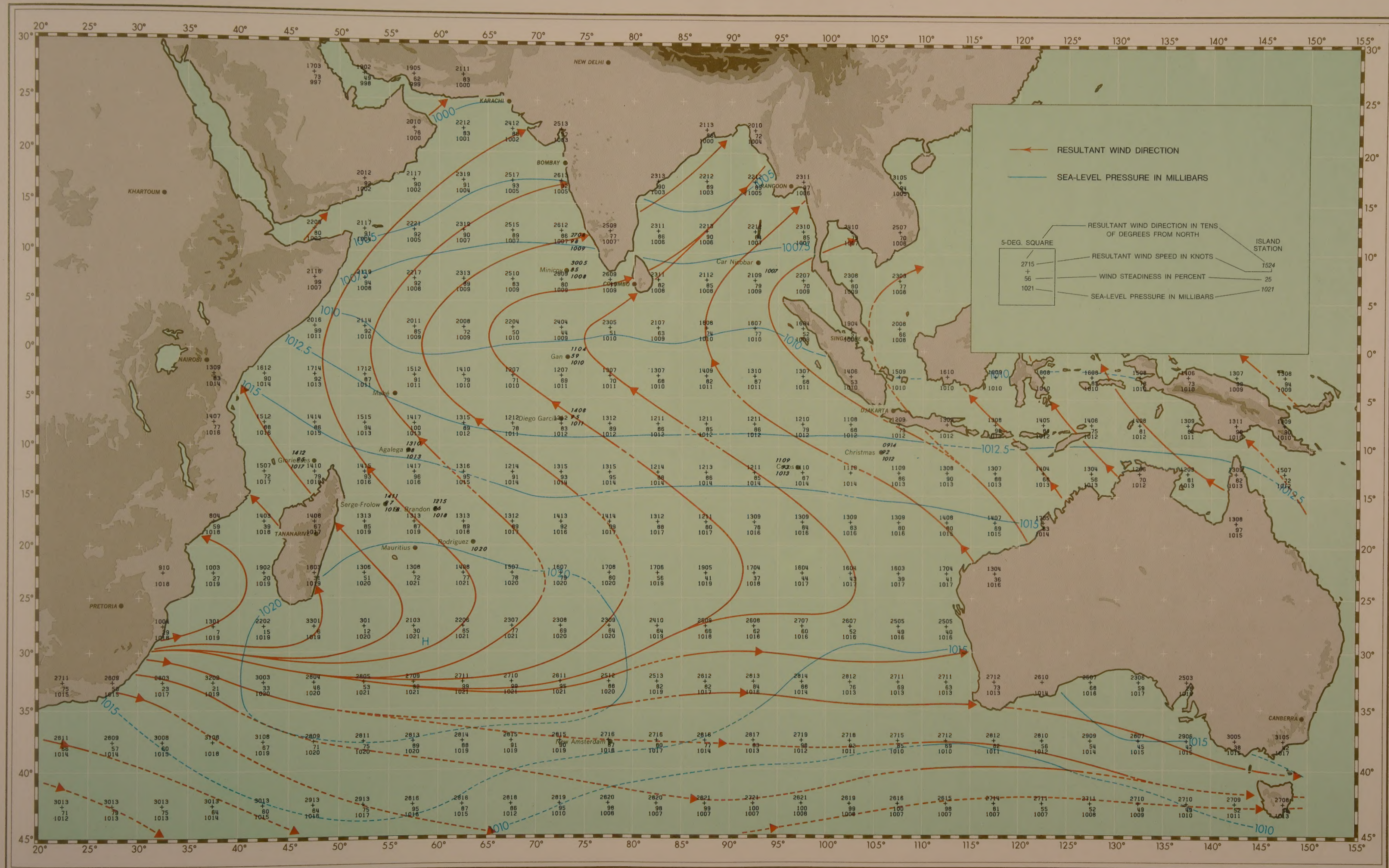


## WINDS AND SEA LEVEL PRESSURE July 1963 Chart 31





# WINDS AND SEA LEVEL PRESSURE August 1963 Chart 32





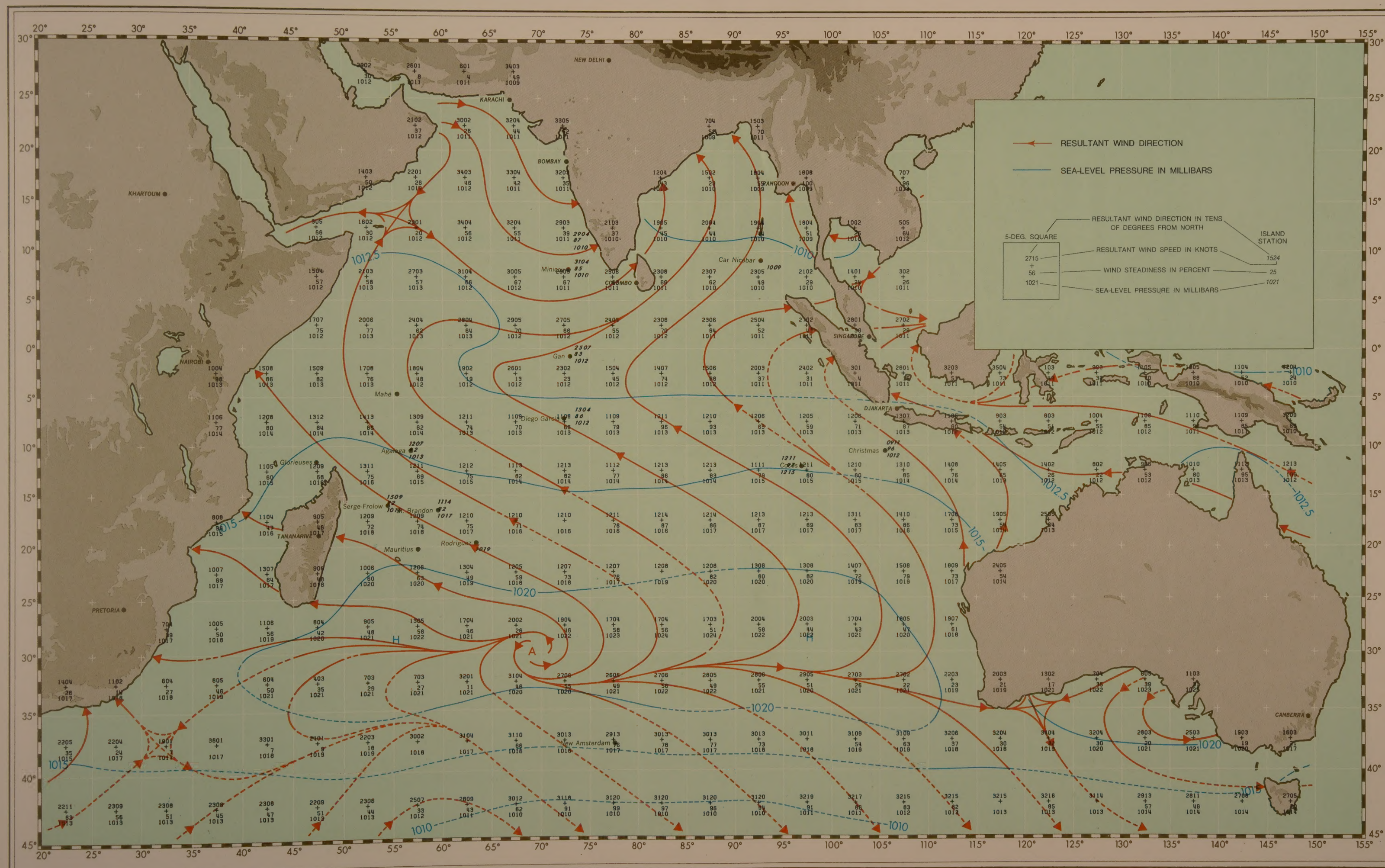
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## WINDS AND SEA LEVEL PRESSURE

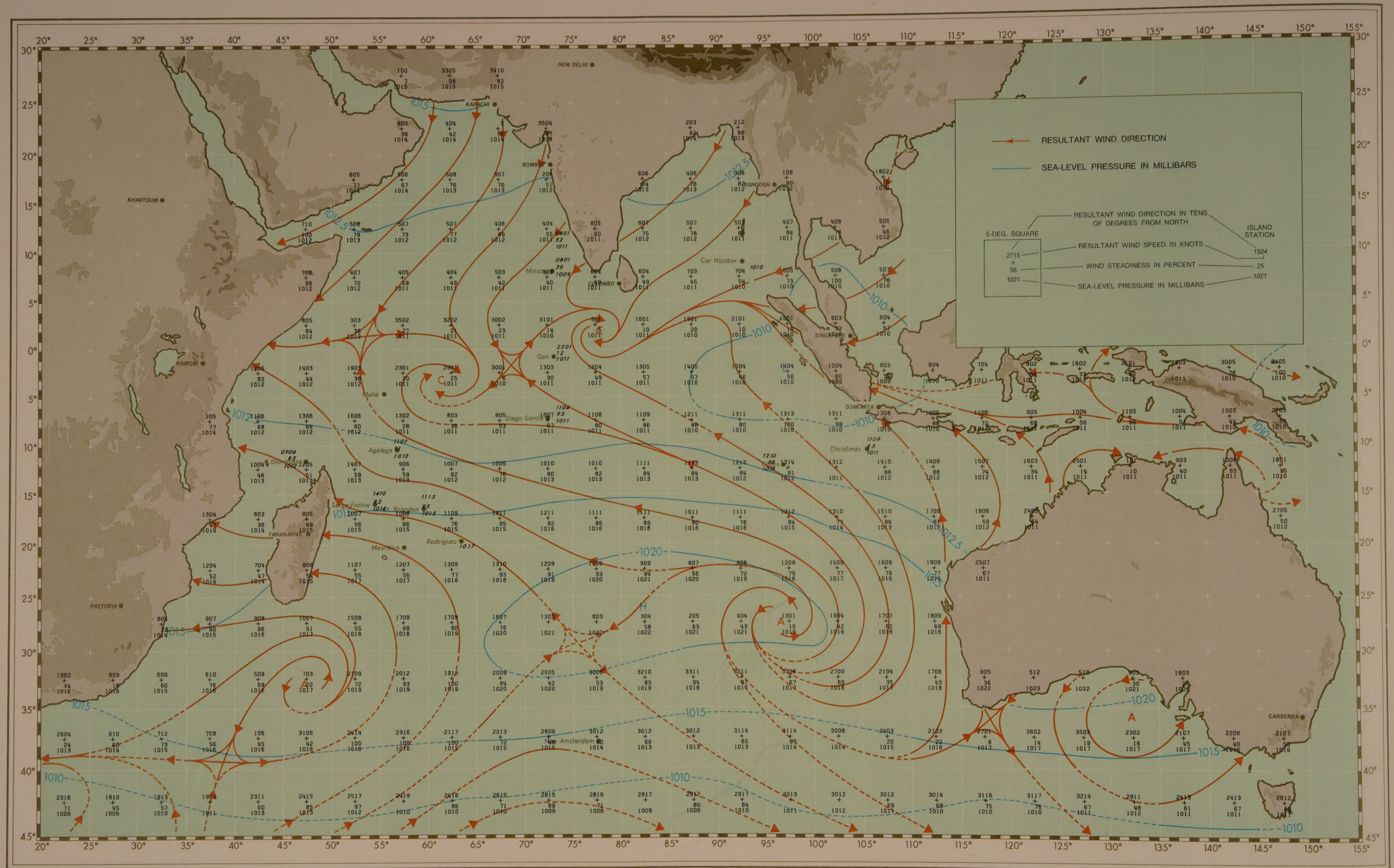
## October 1963

### Chart 34



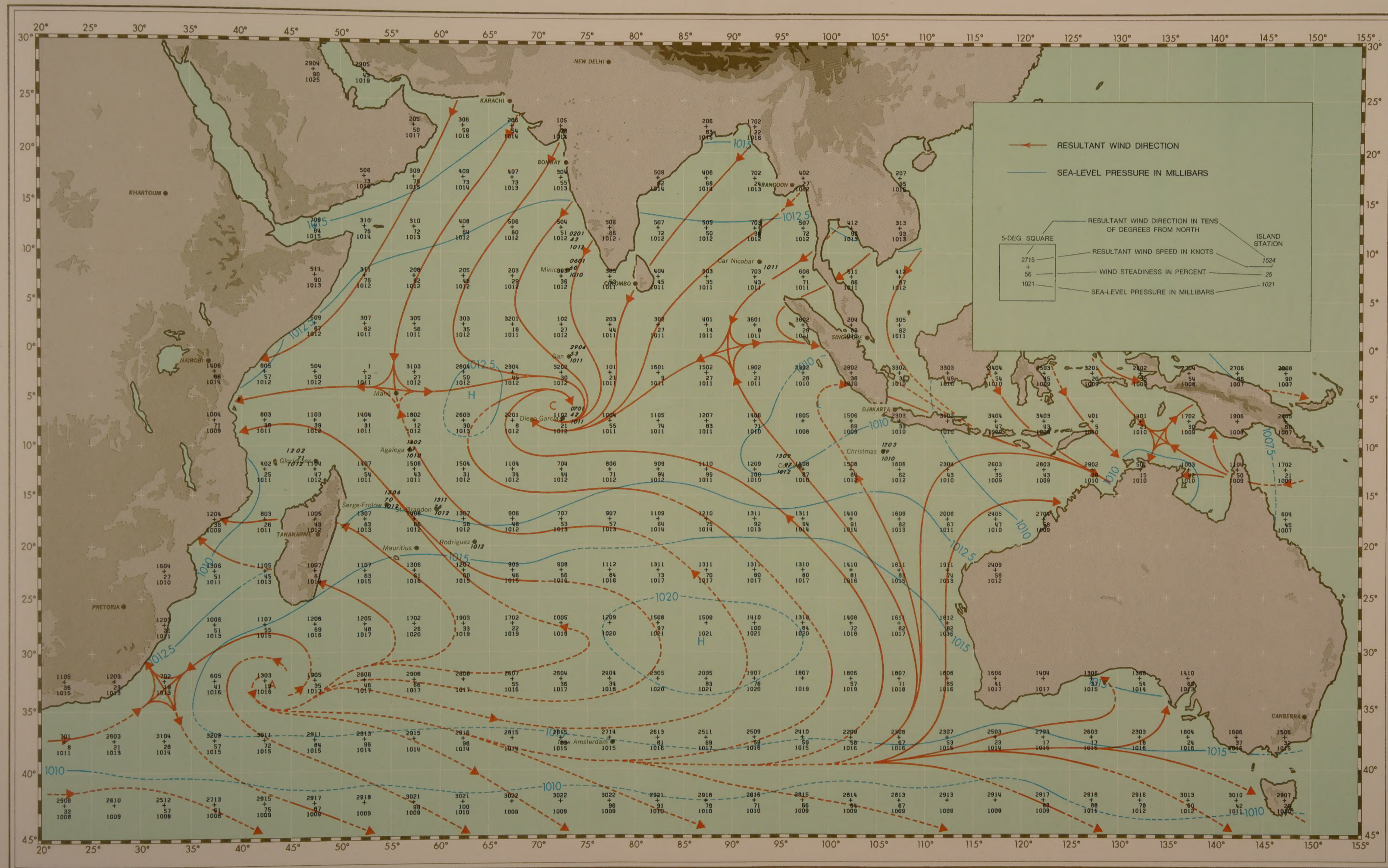


# WINDS AND SEA LEVEL PRESSURE November 1963 Chart 35





### Chart 36

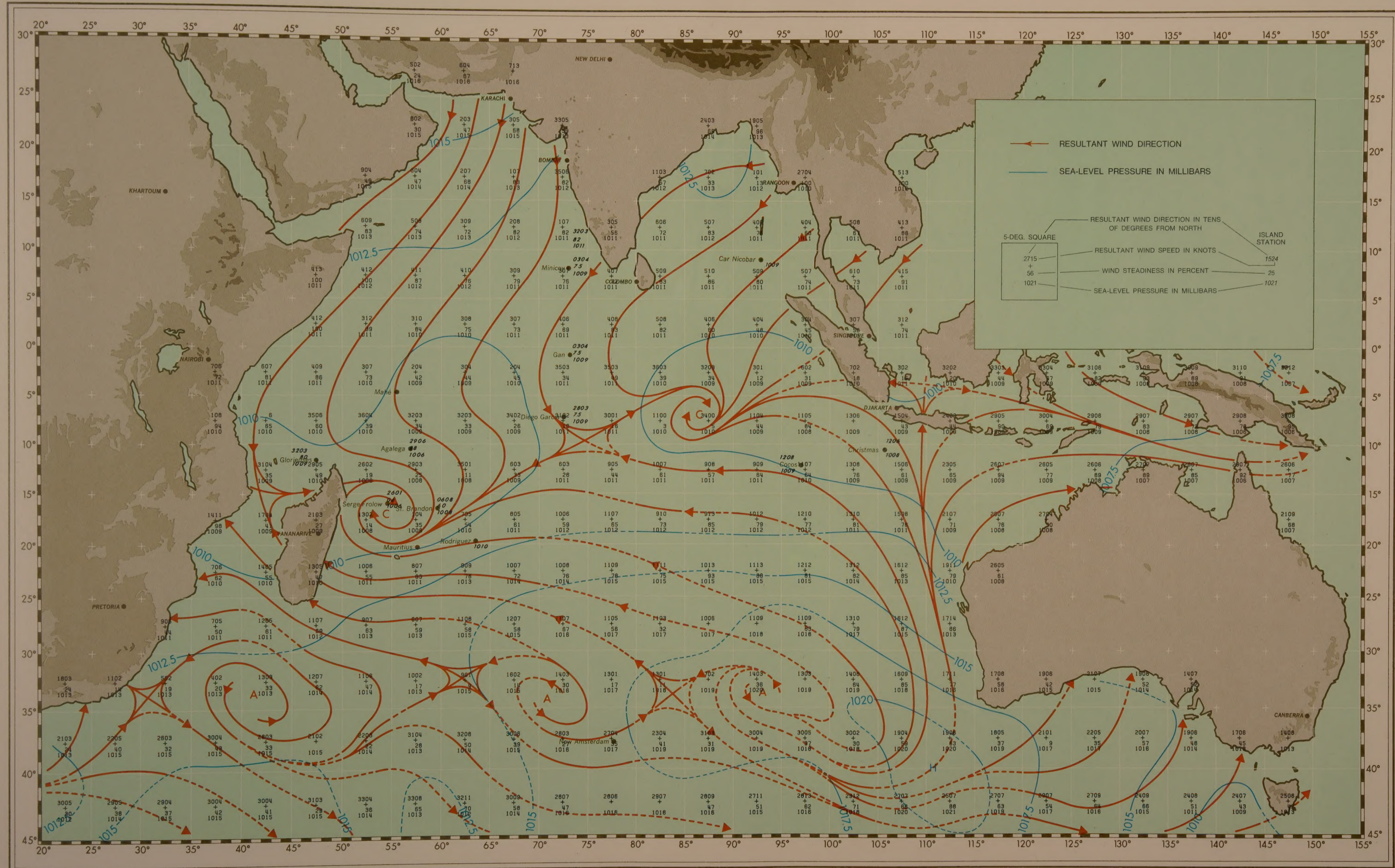




## WINDS AND SEA LEVEL PRESSURE January 1964 Chart 37

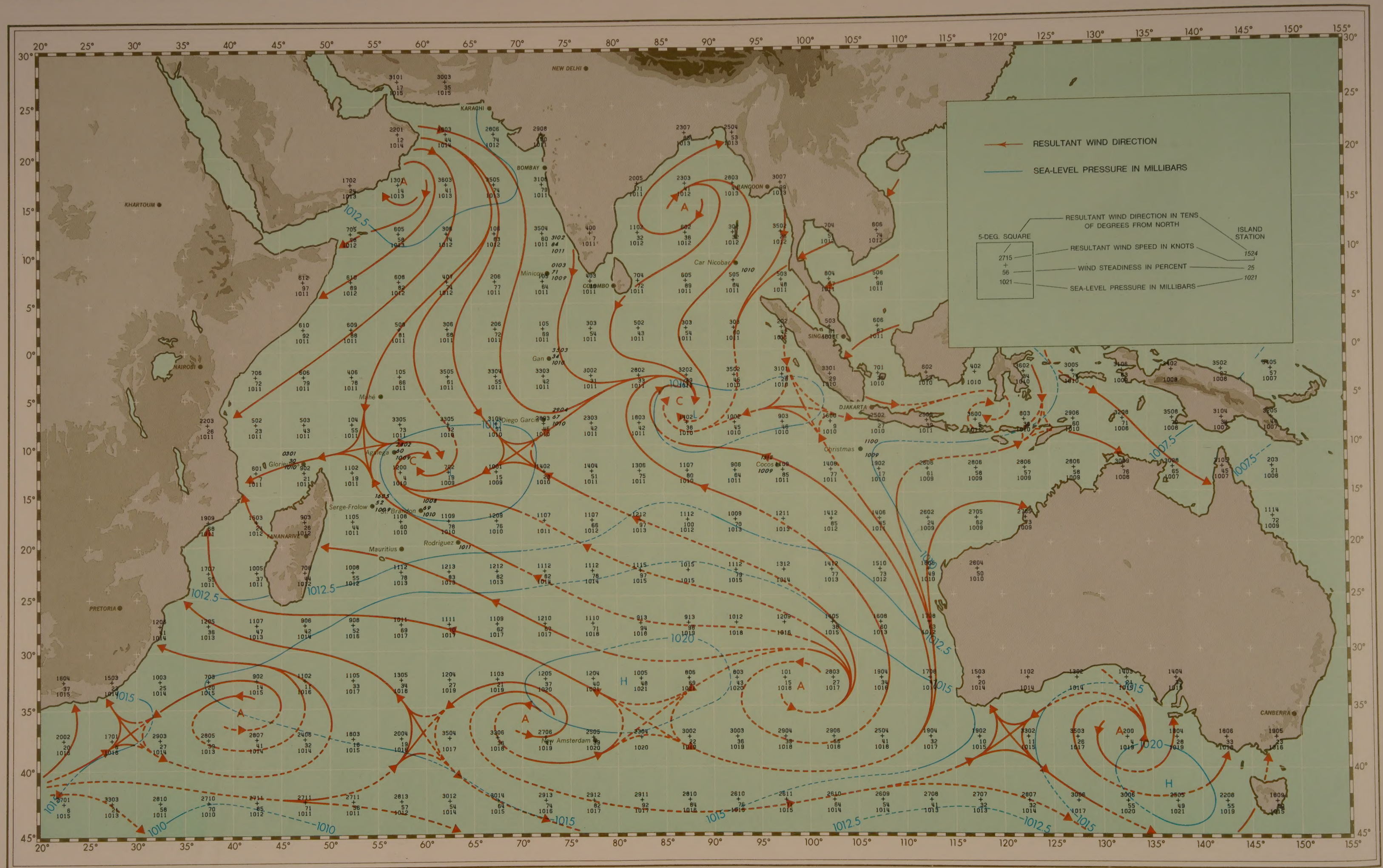


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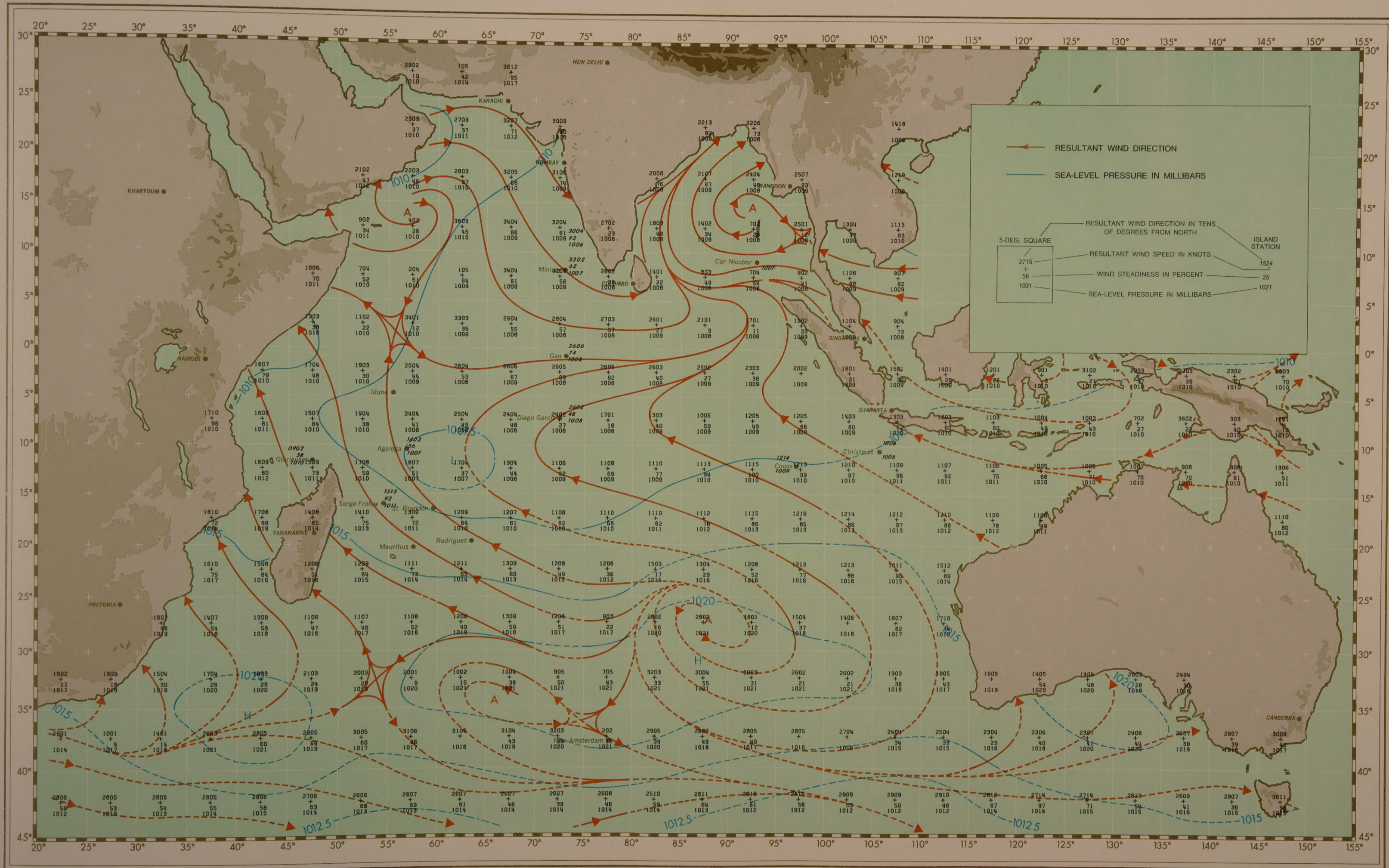


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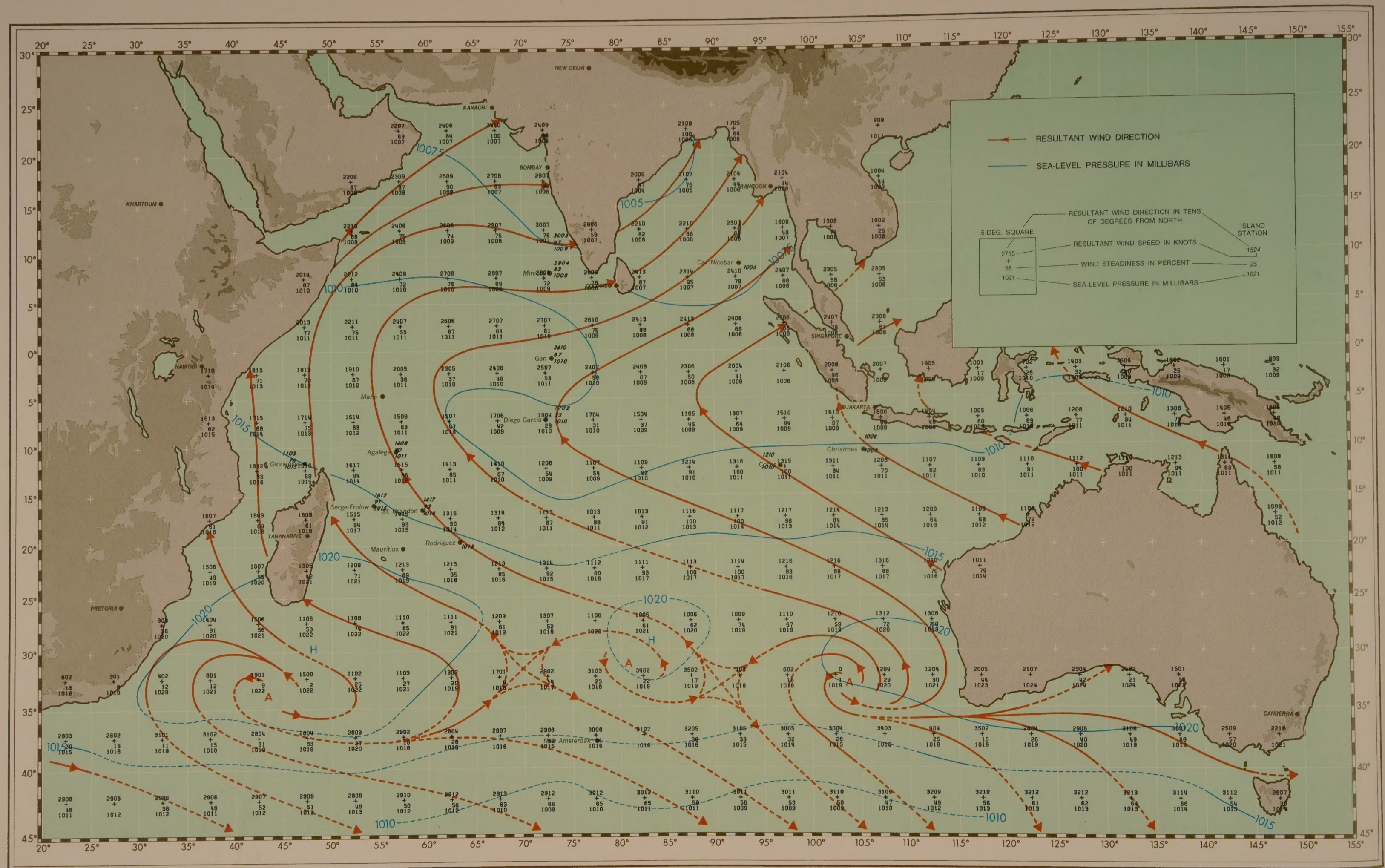


# WINDS AND SEA LEVEL PRESSURE April 1964 Chart 40



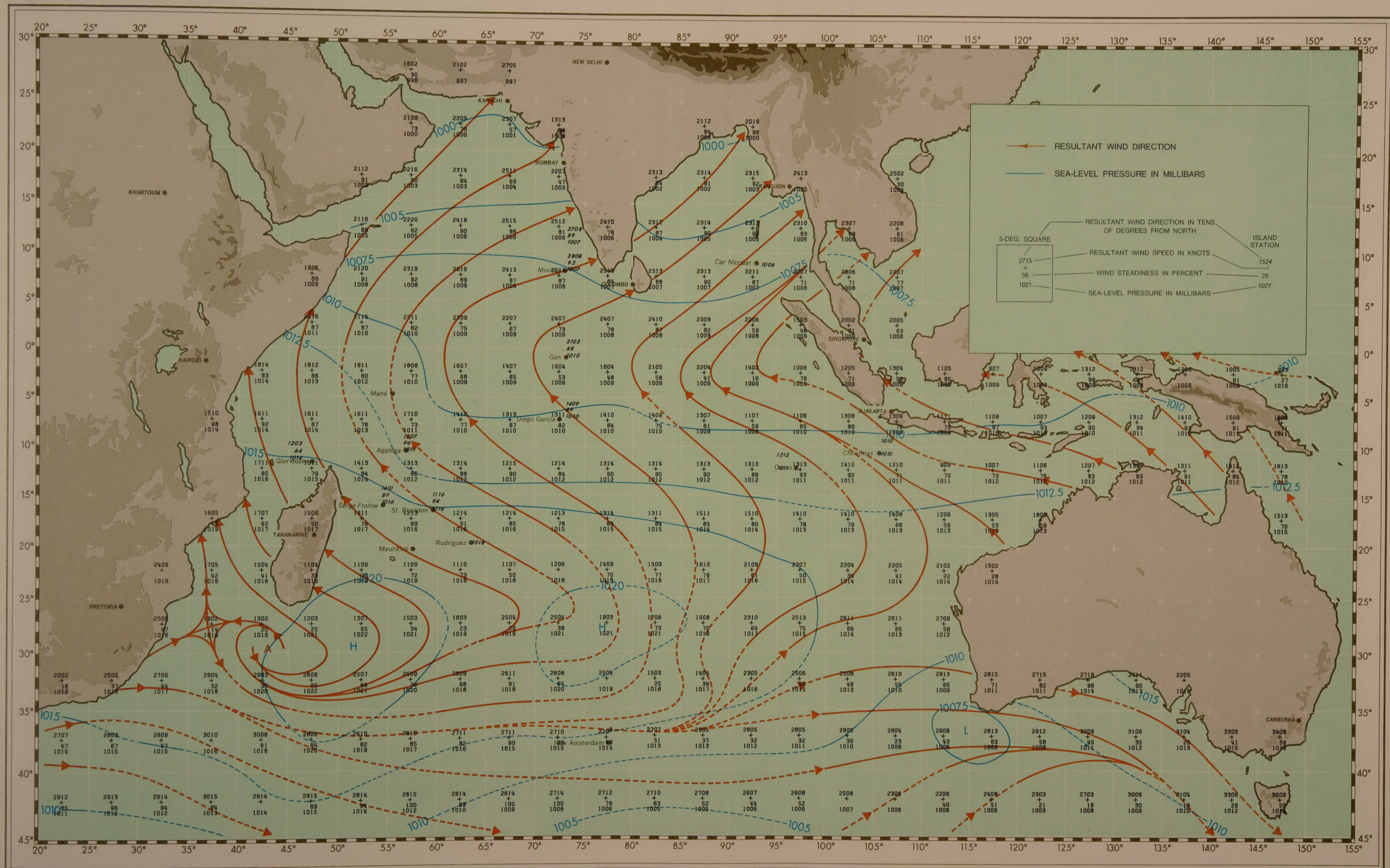


# WINDS AND SEA LEVEL PRESSURE May 1964 Chart 41



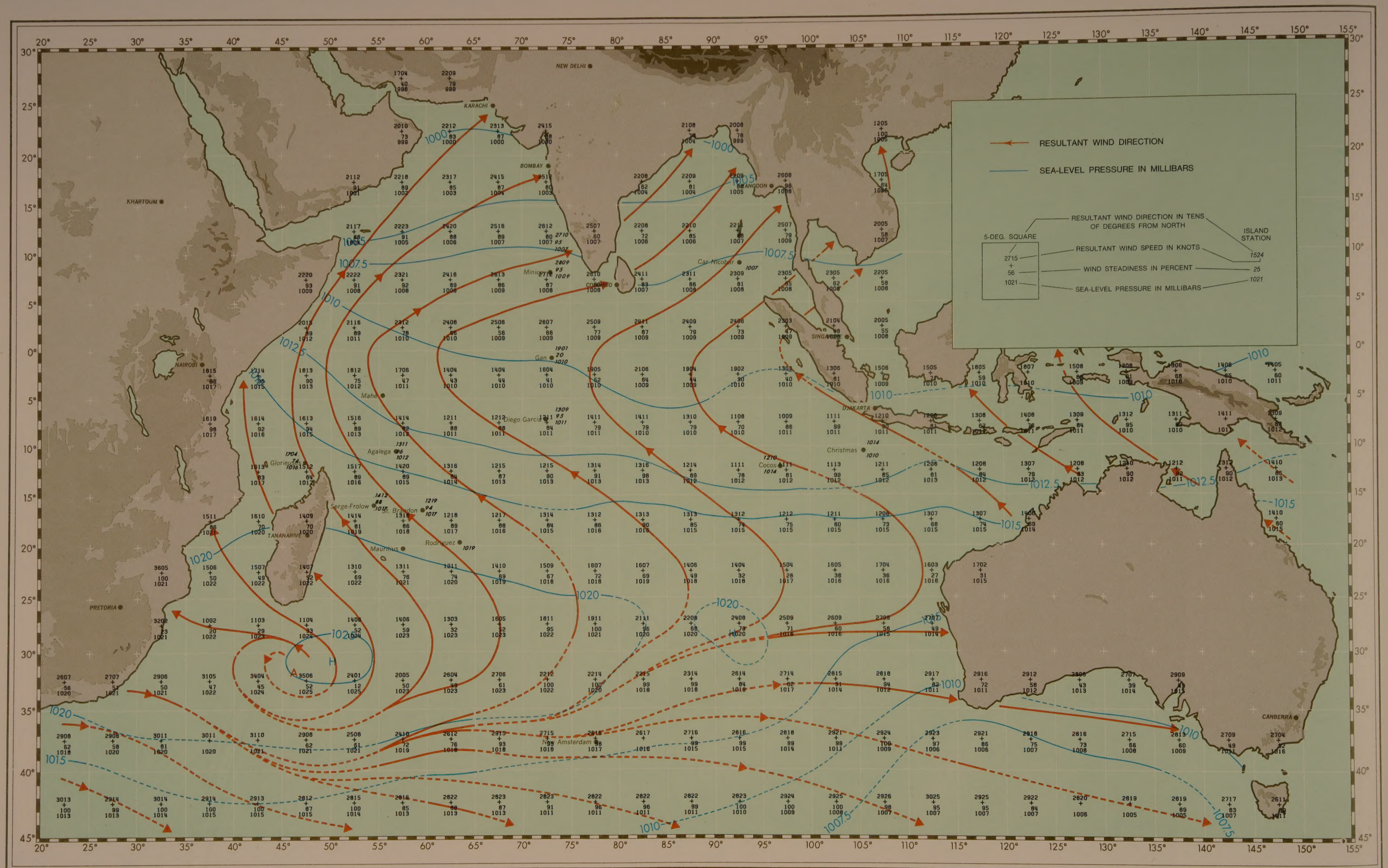


# WINDS AND SEA LEVEL PRESSURE June 1964 Chart 42



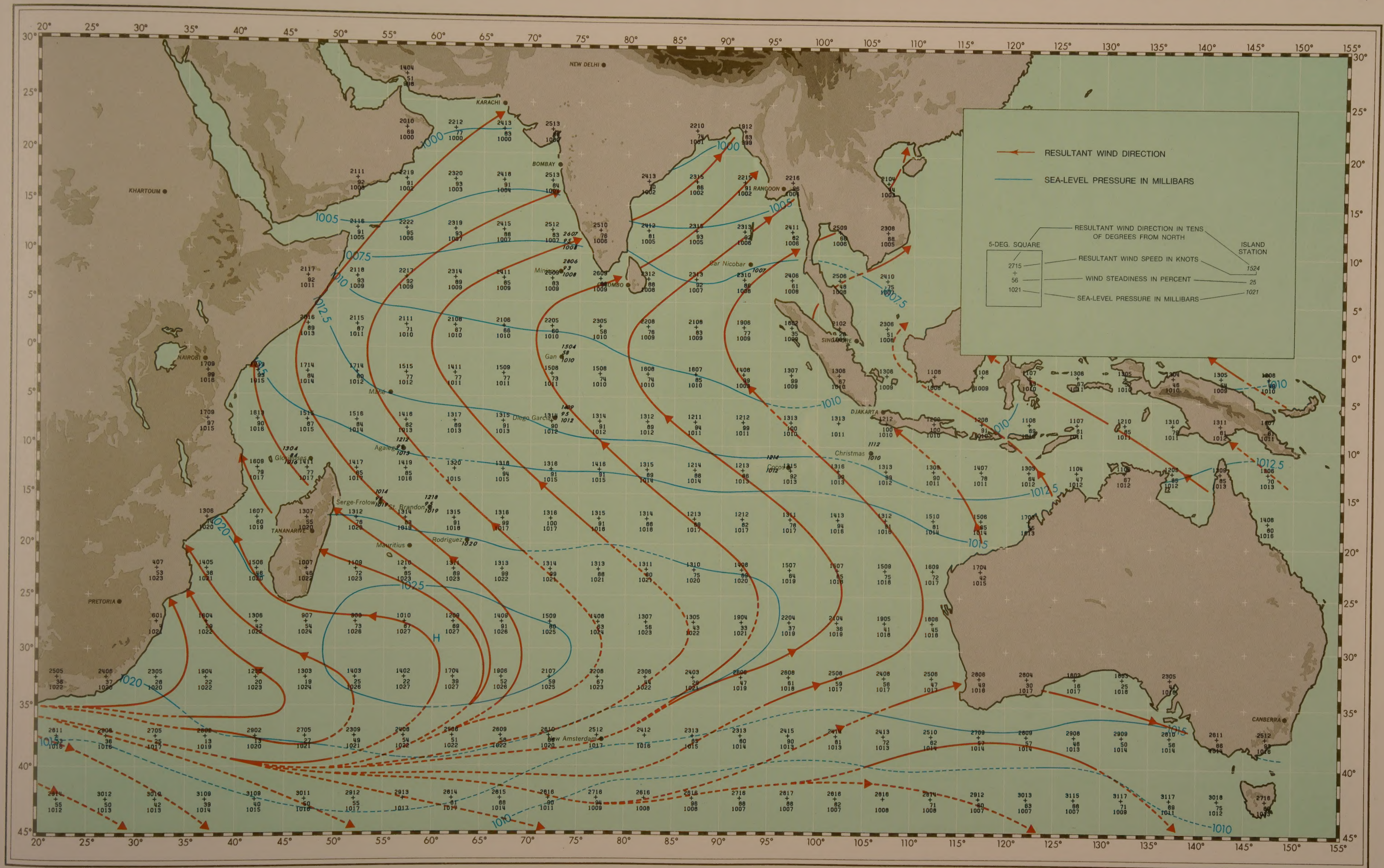


# WINDS AND SEA LEVEL PRESSURE July 1964 Chart 43



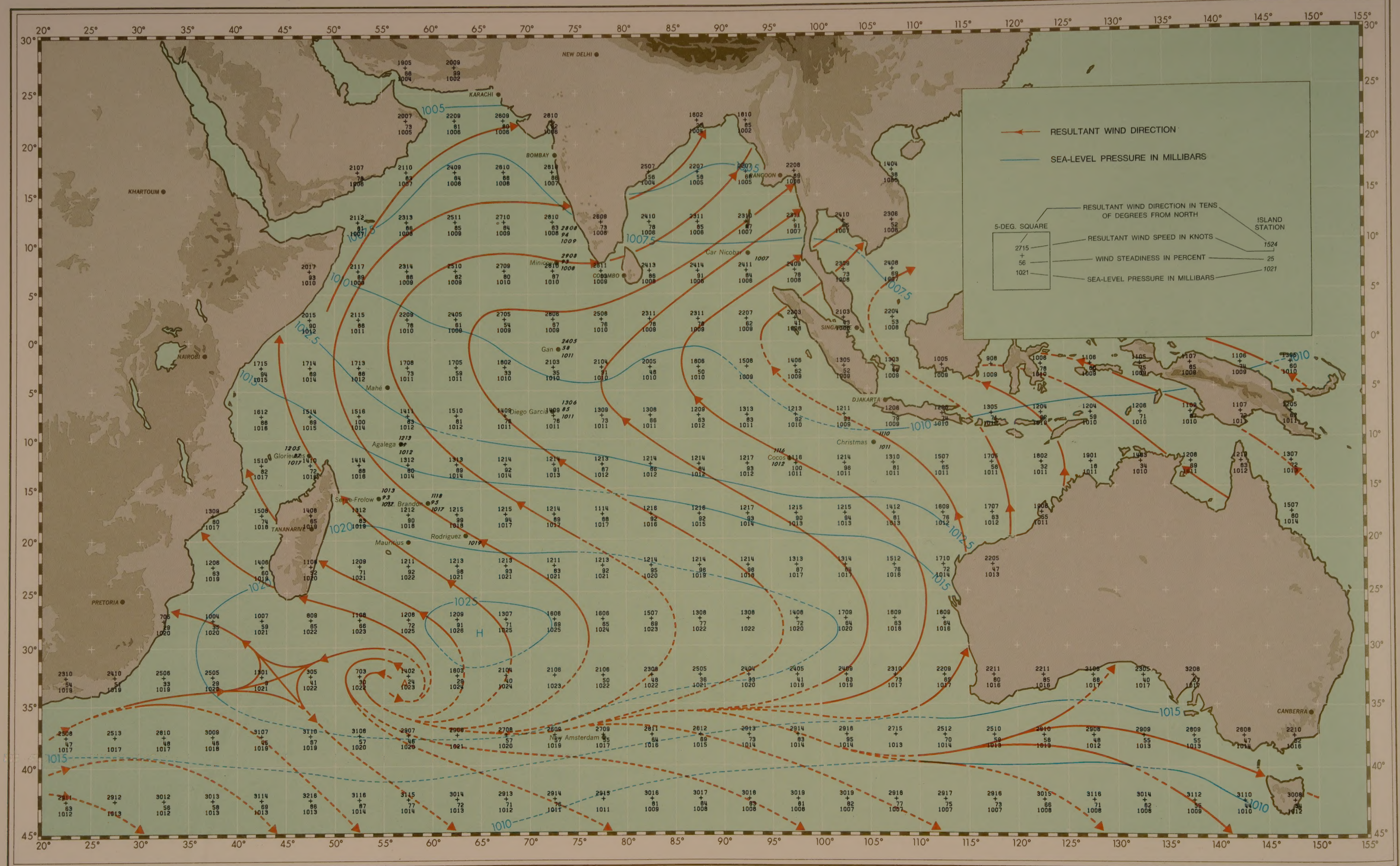


# WINDS AND SEA LEVEL PRESSURE August 1964 Chart 44



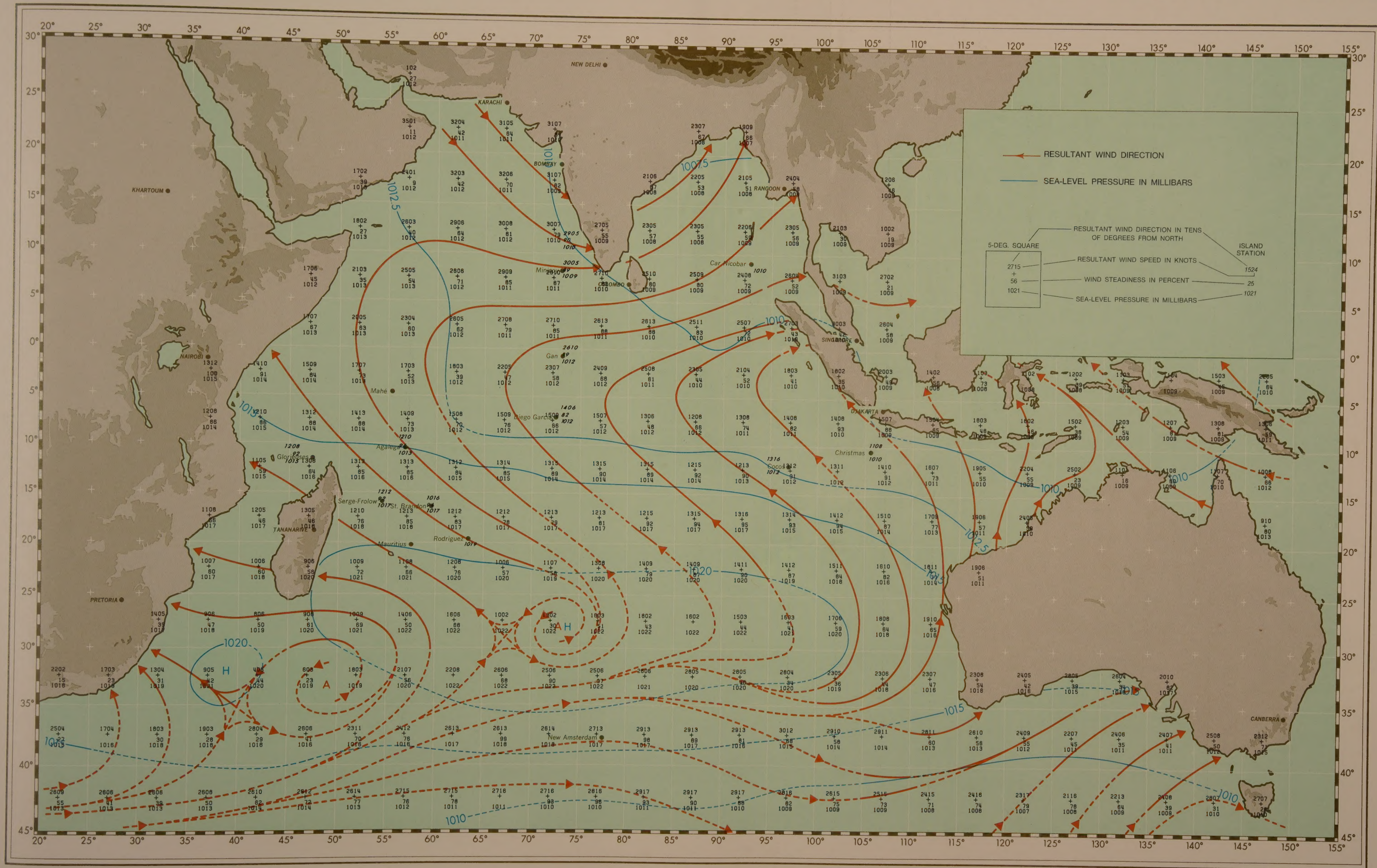


# WINDS AND SEA LEVEL PRESSURE September 1964 Chart 45



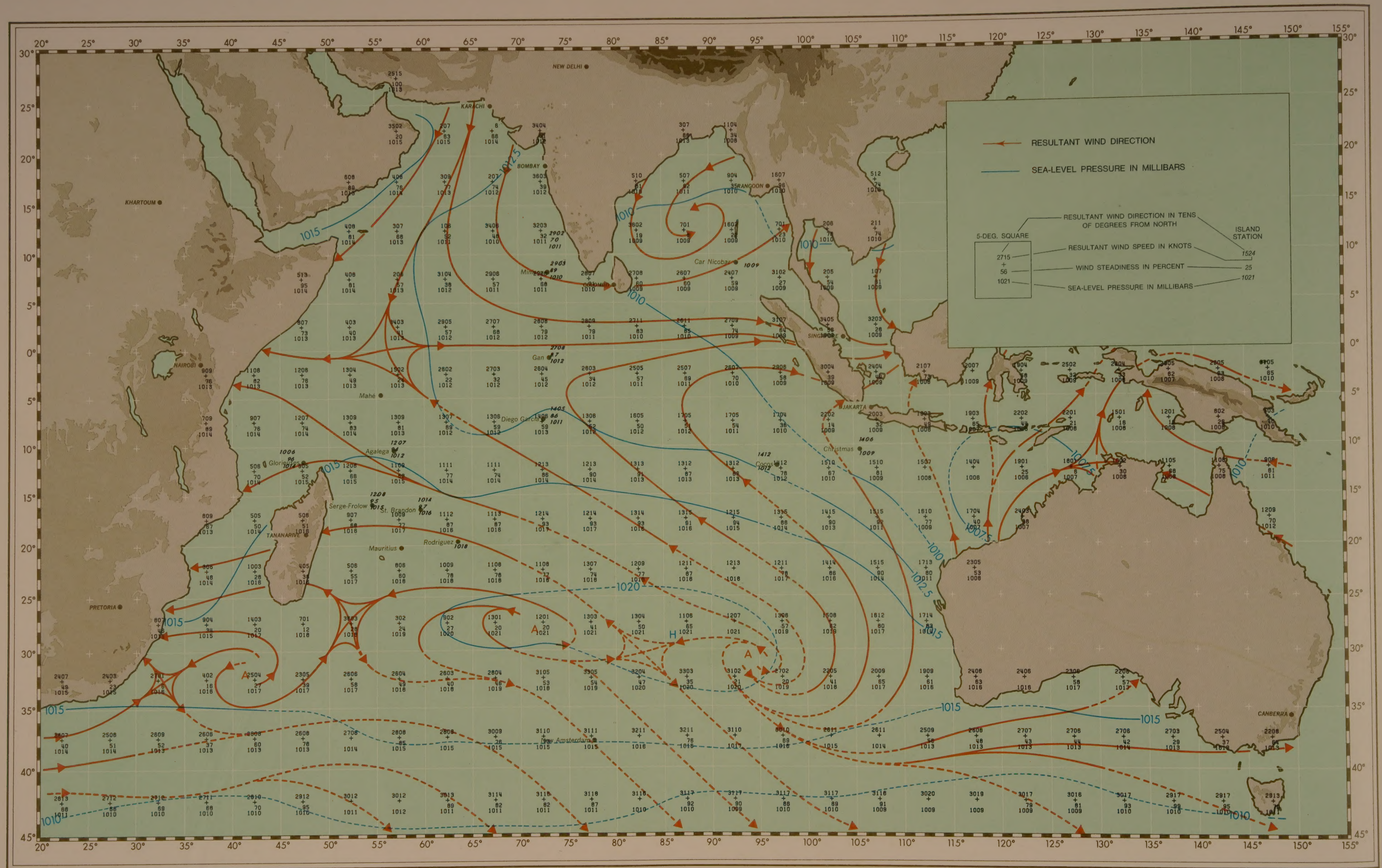


# WINDS AND SEA LEVEL PRESSURE October 1964 Chart 46



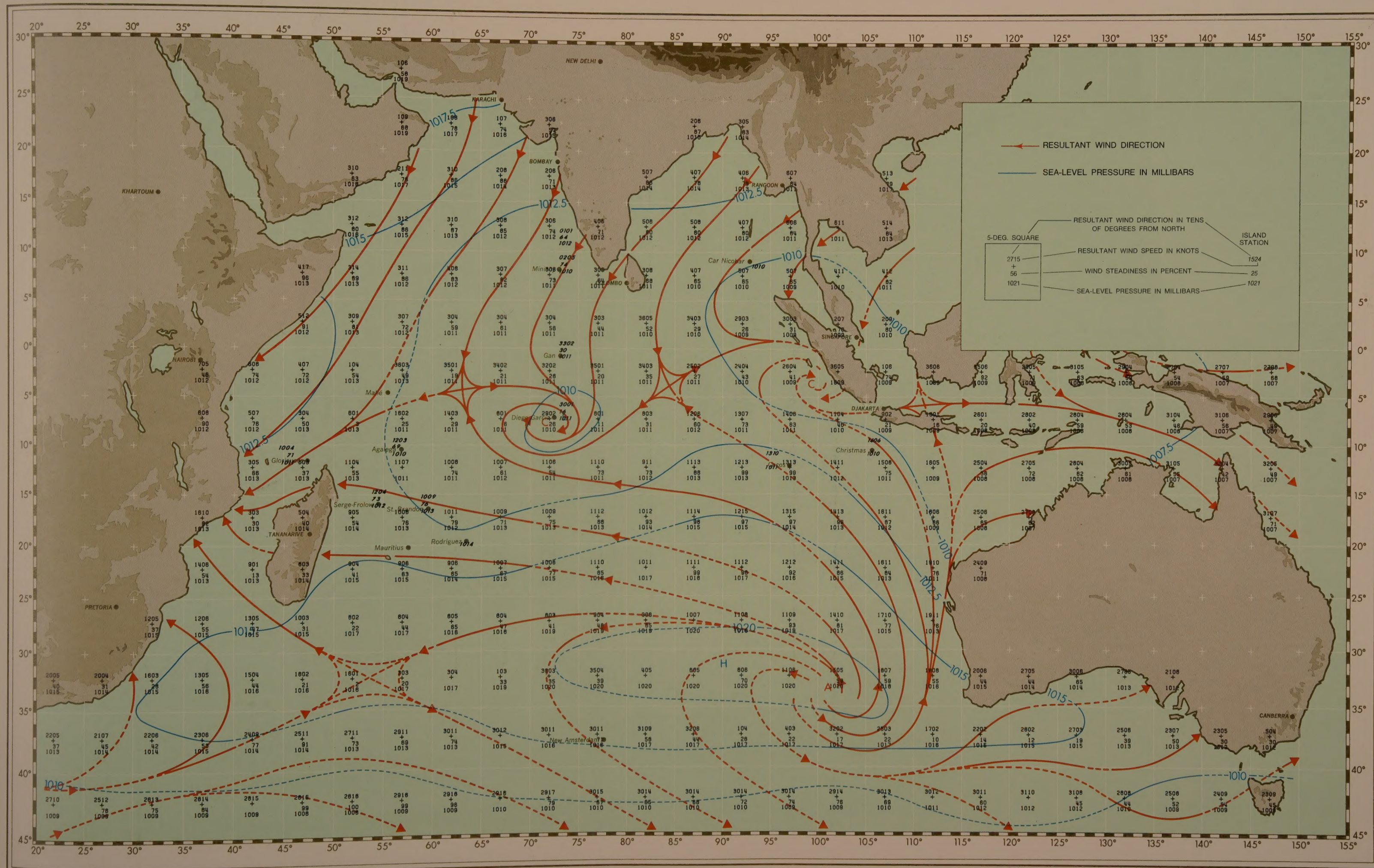


# WINDS AND SEA LEVEL PRESSURE November 1964 Chart 47





# WINDS AND SEA LEVEL PRESSURE December 1964 Chart 48





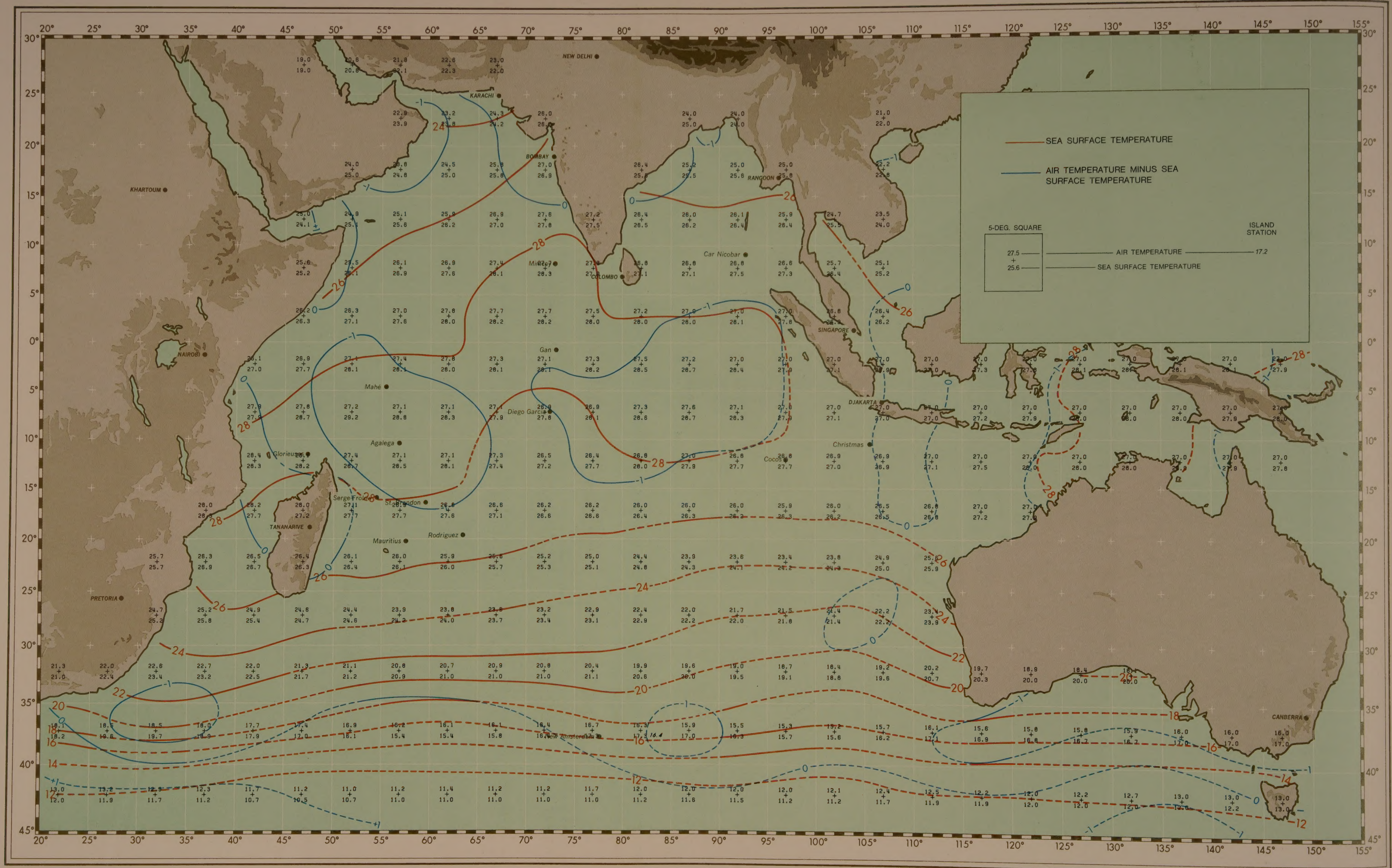




# Air and Sea Surface Temperatures

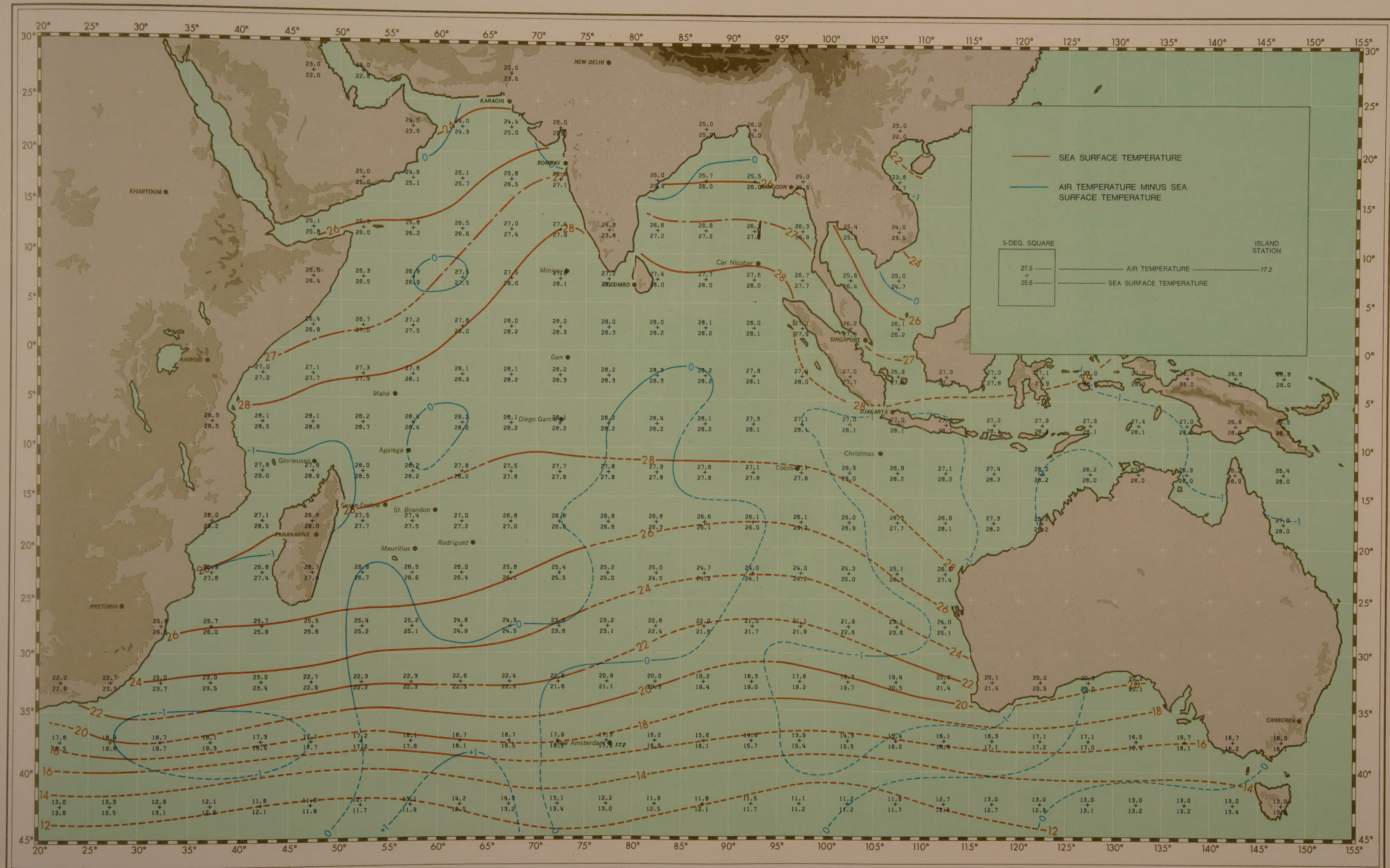


# AIR AND SEA SURFACE TEMPERATURES IN °C January 1963 Chart 49



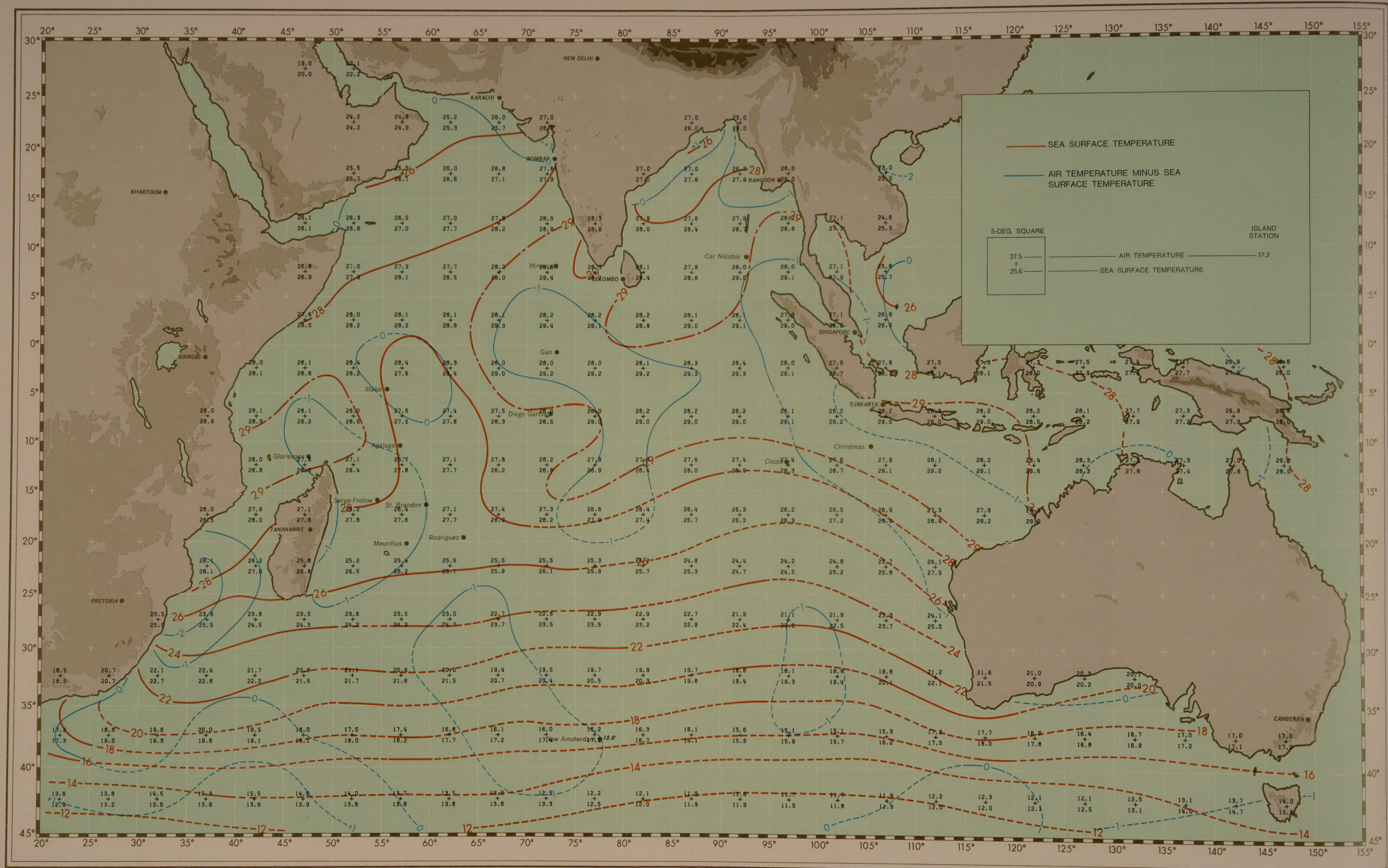


# AIR AND SEA SURFACE TEMPERATURES IN °C February 1963 Chart 50



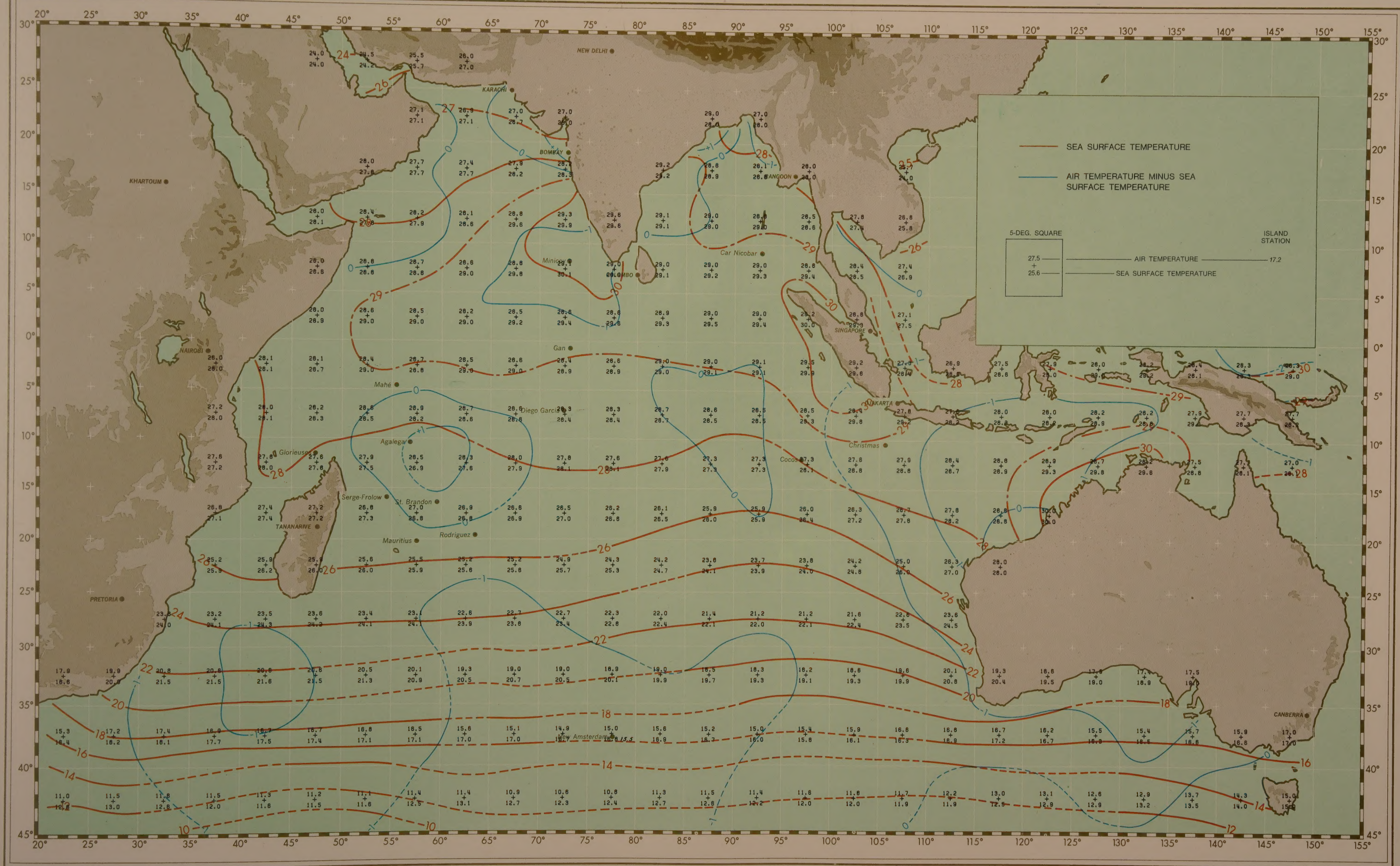


# AIR AND SEA SURFACE TEMPERATURES IN °C March 1963 Chart 51



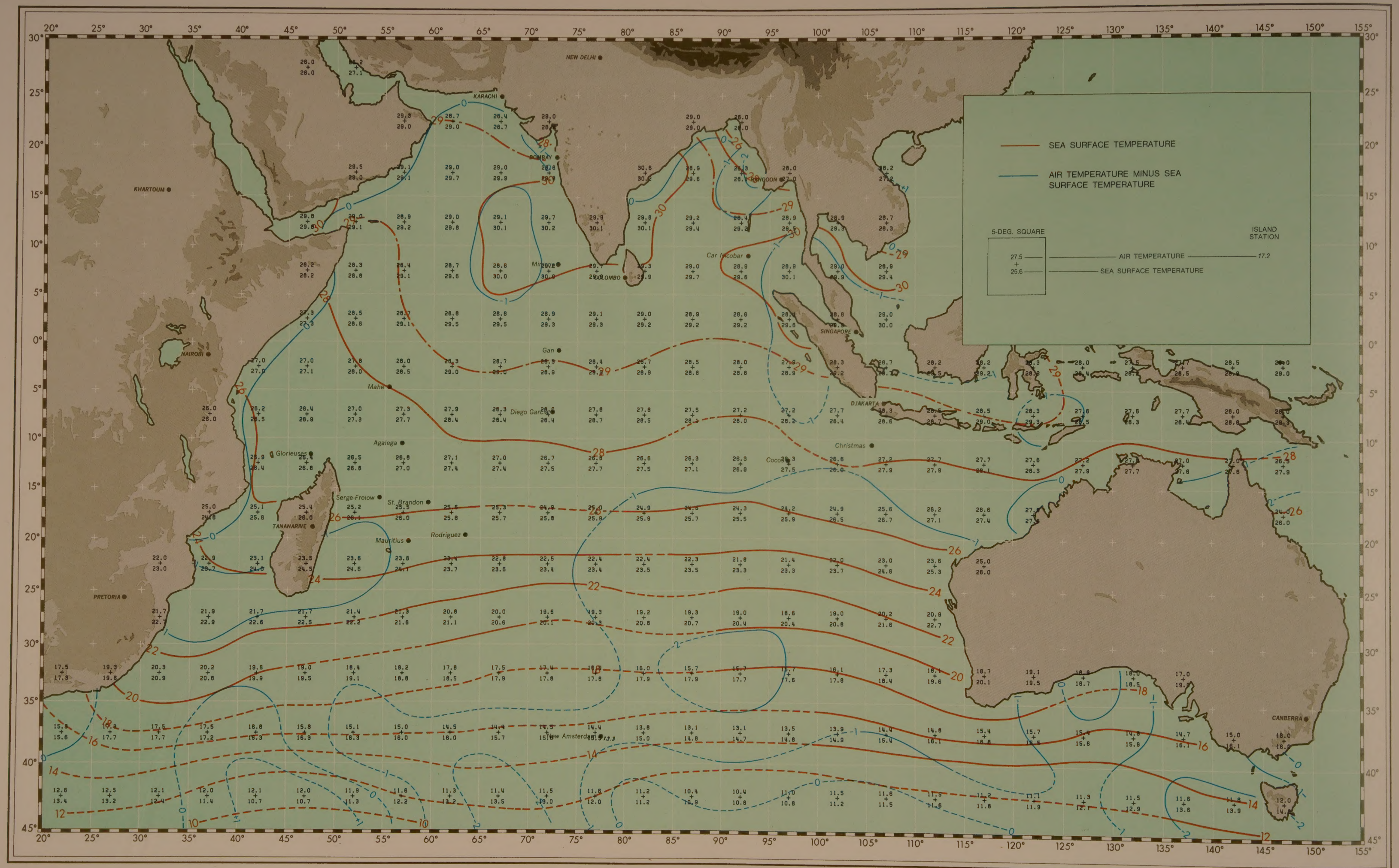


# AIR AND SEA SURFACE TEMPERATURES IN °C April 1963 Chart 52



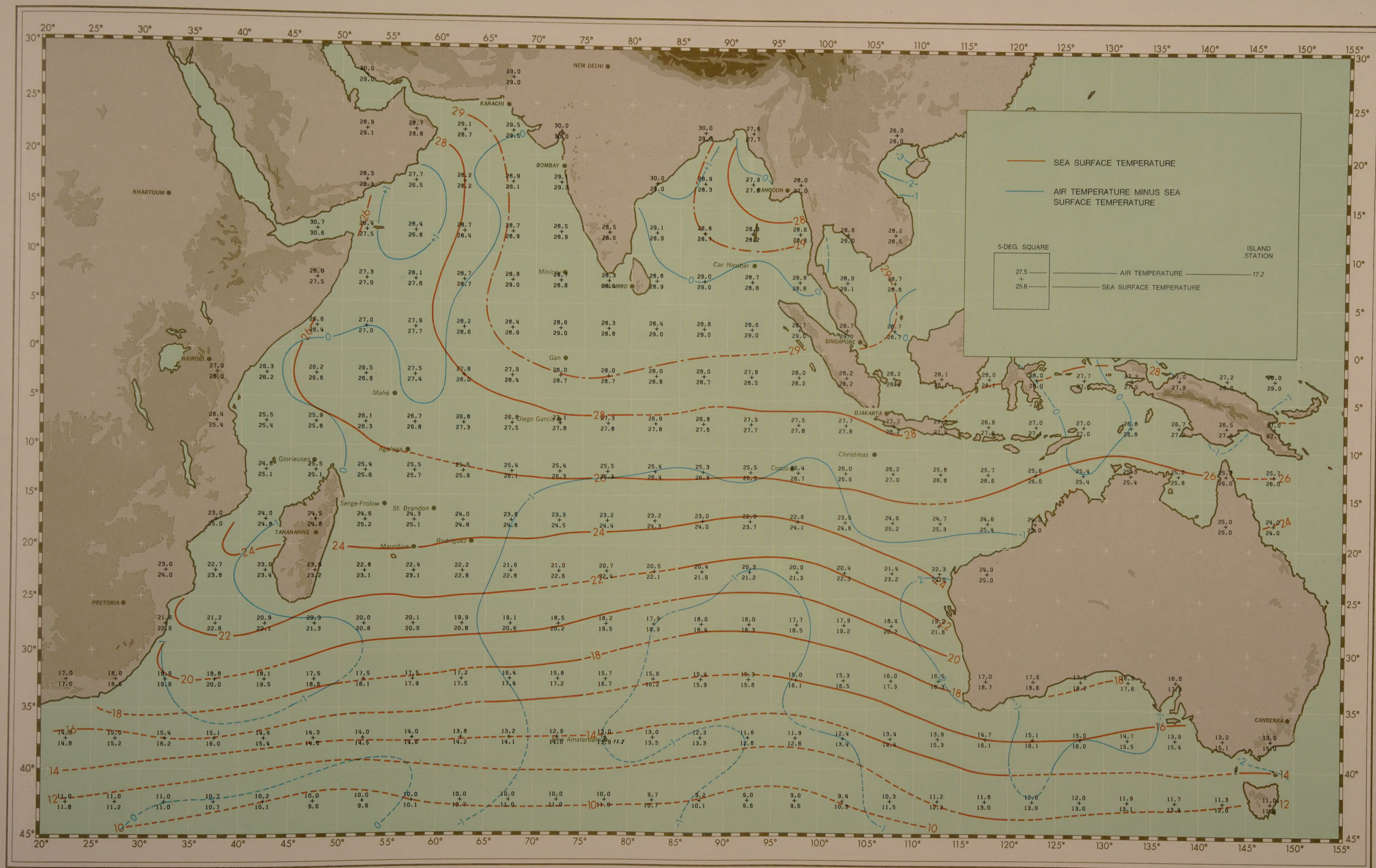


# AIR AND SEA SURFACE TEMPERATURES IN °C May 1963 Chart 53



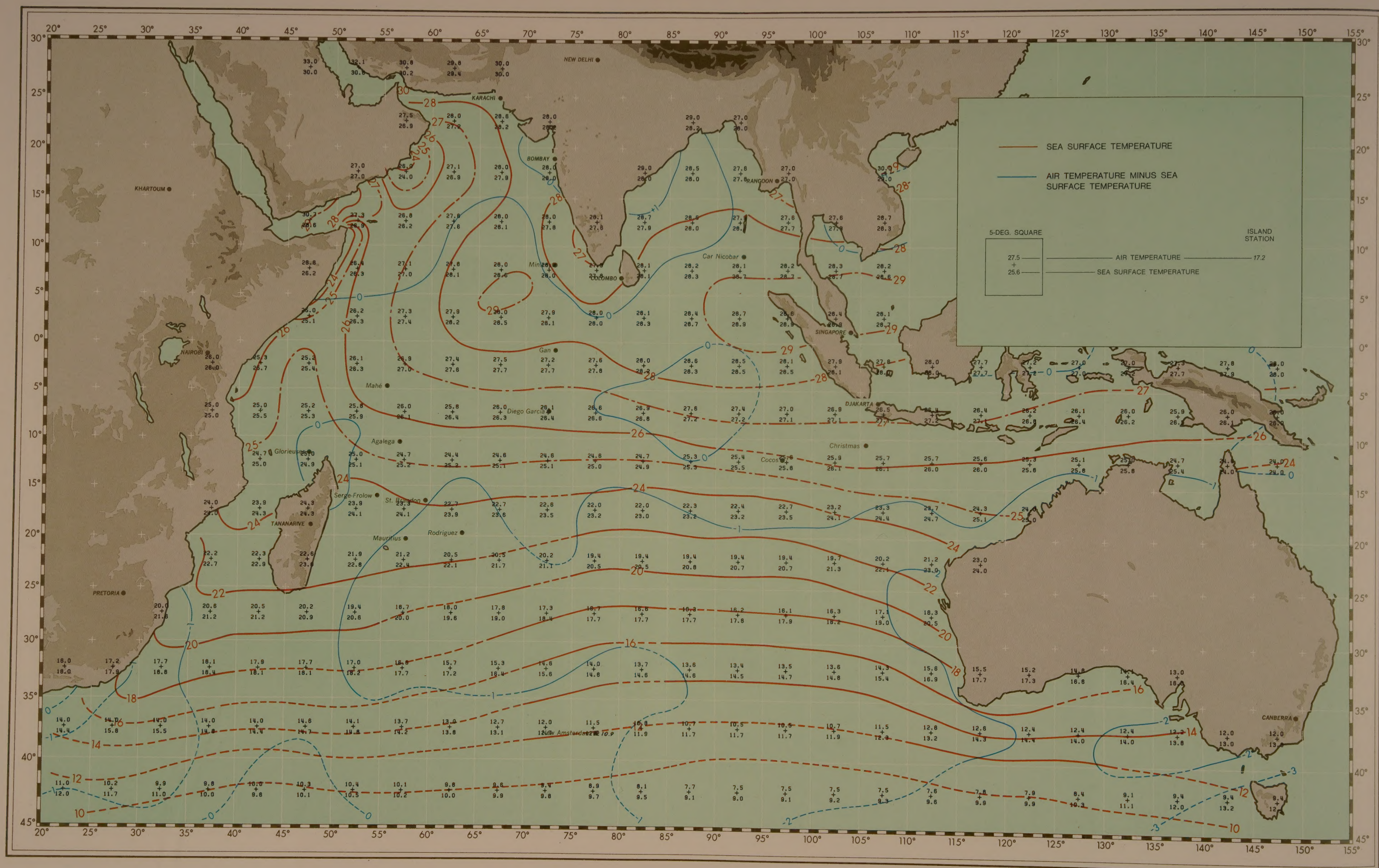


### Chart 54



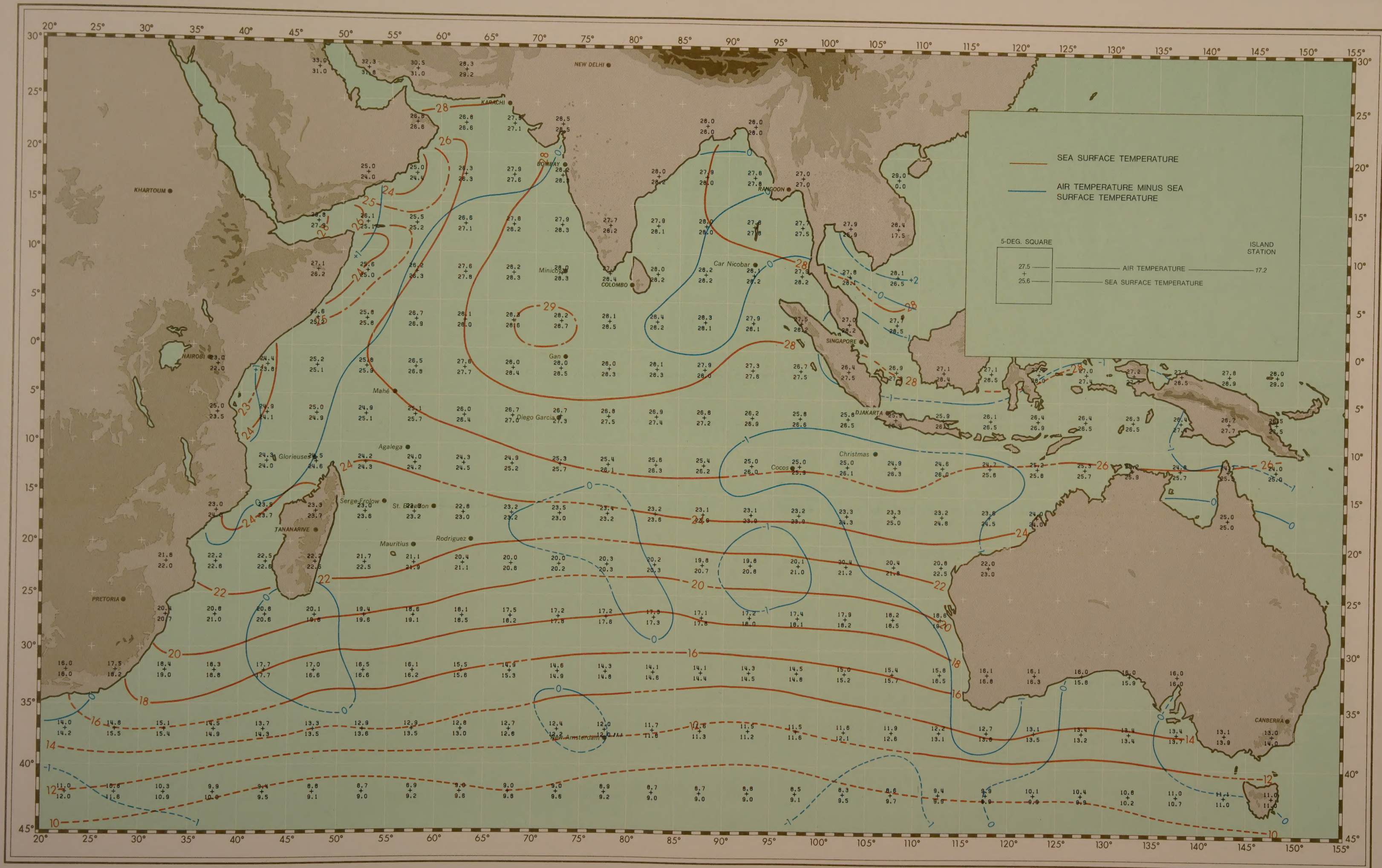


# AIR AND SEA SURFACE TEMPERATURES IN °C July 1963 Chart 55



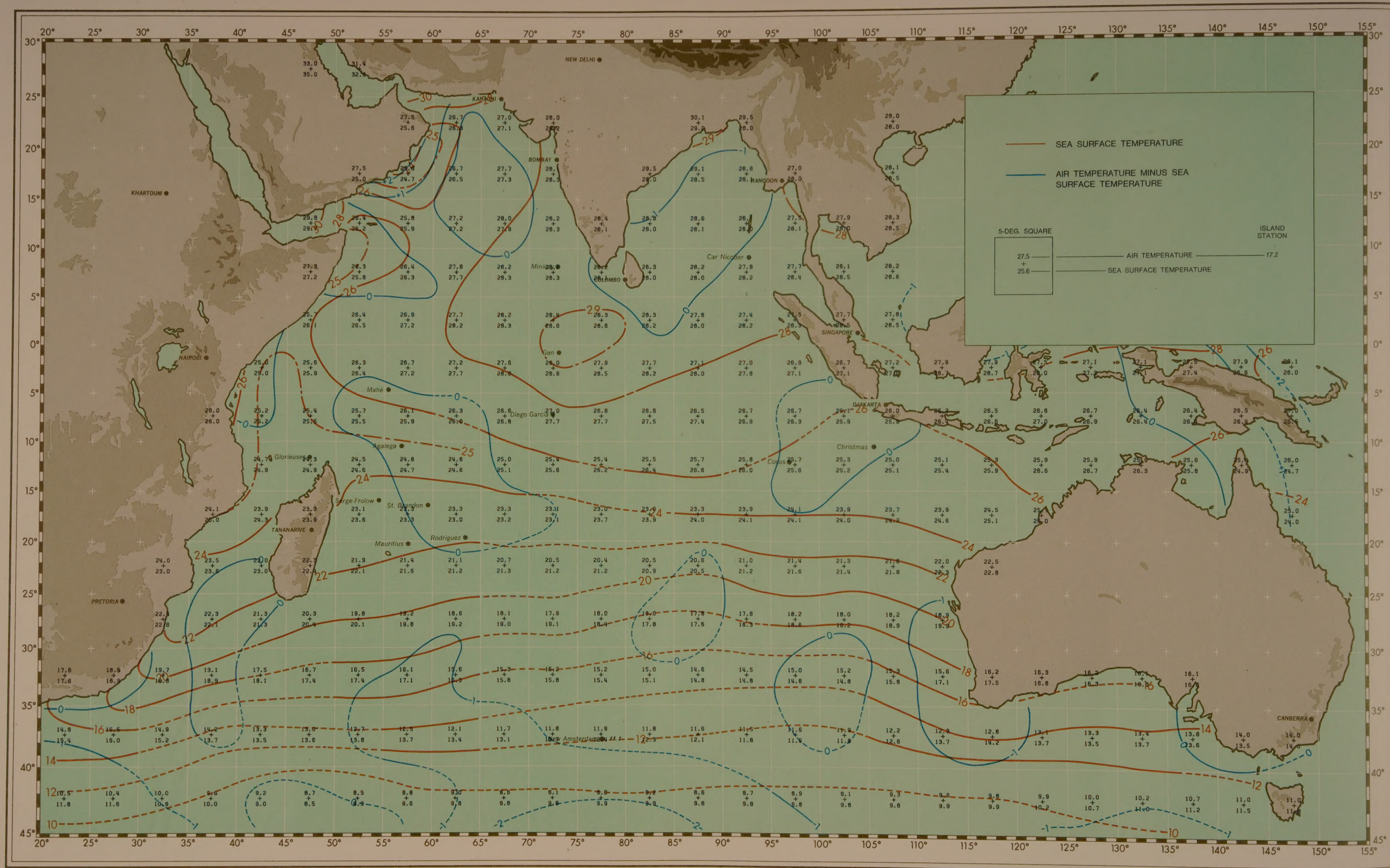


# AIR AND SEA SURFACE TEMPERATURES IN °C August 1963 Chart 56



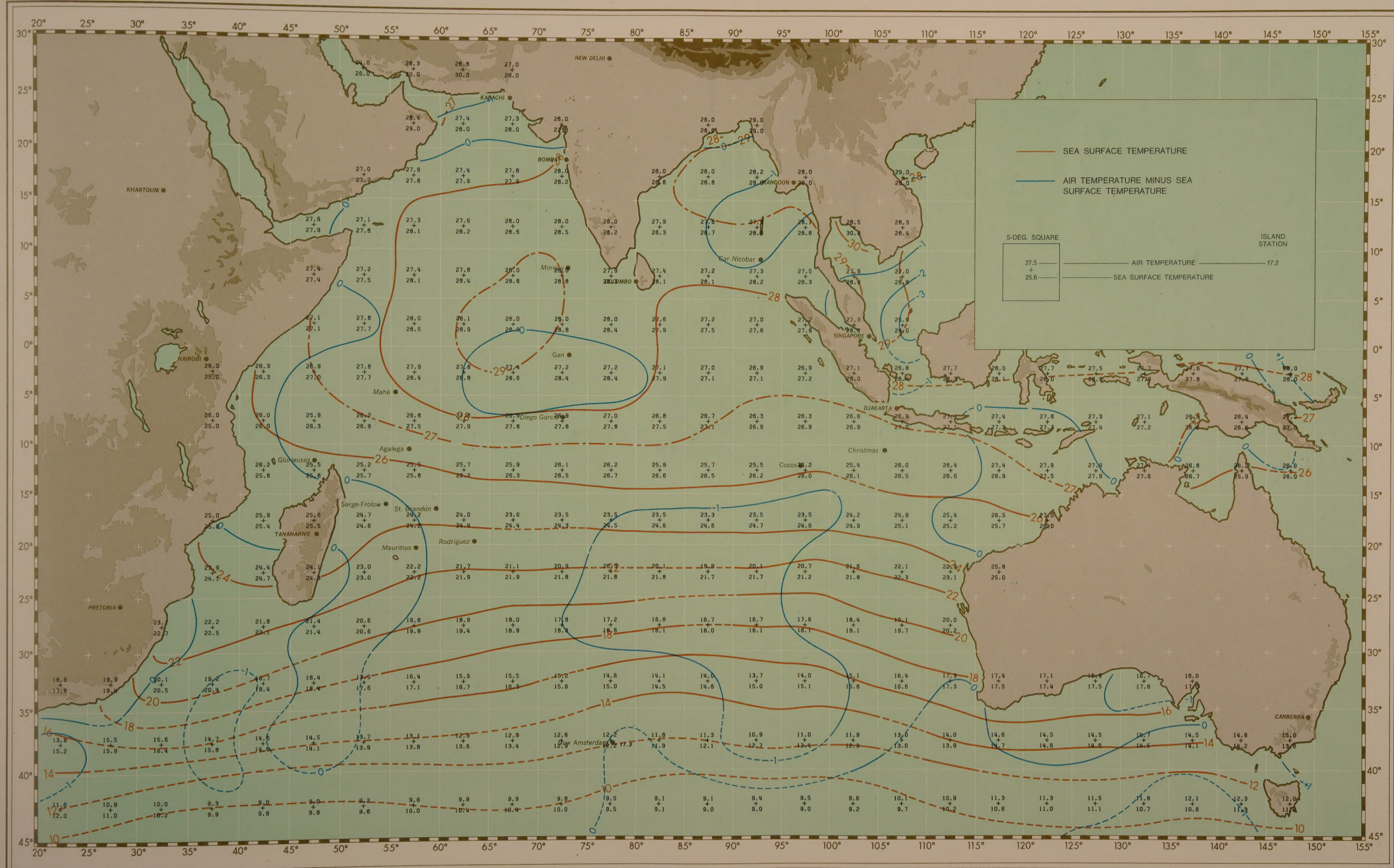


## Chart 57



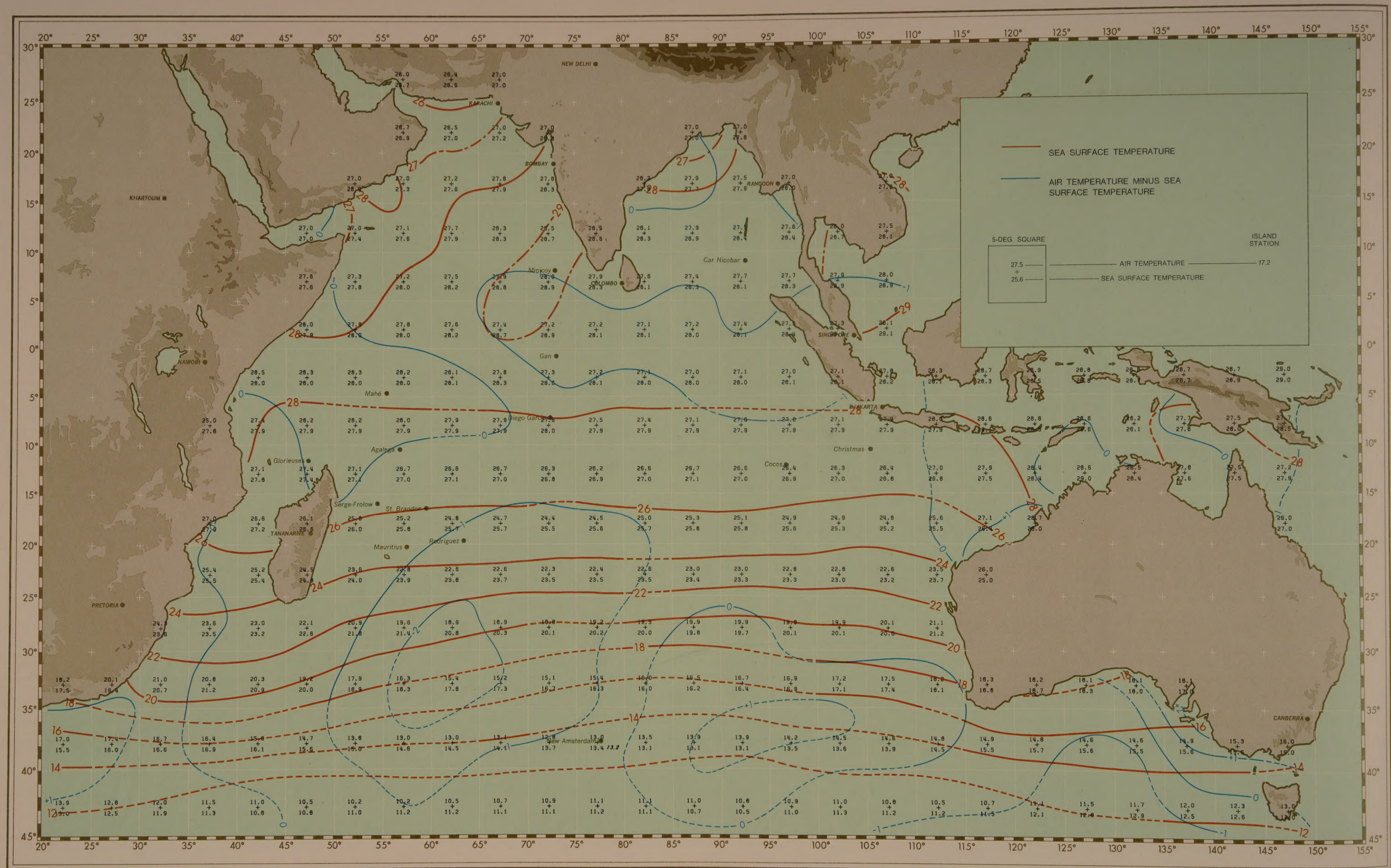


# AIR AND SEA SURFACE TEMPERATURES IN °C    October 1963    Chart 58



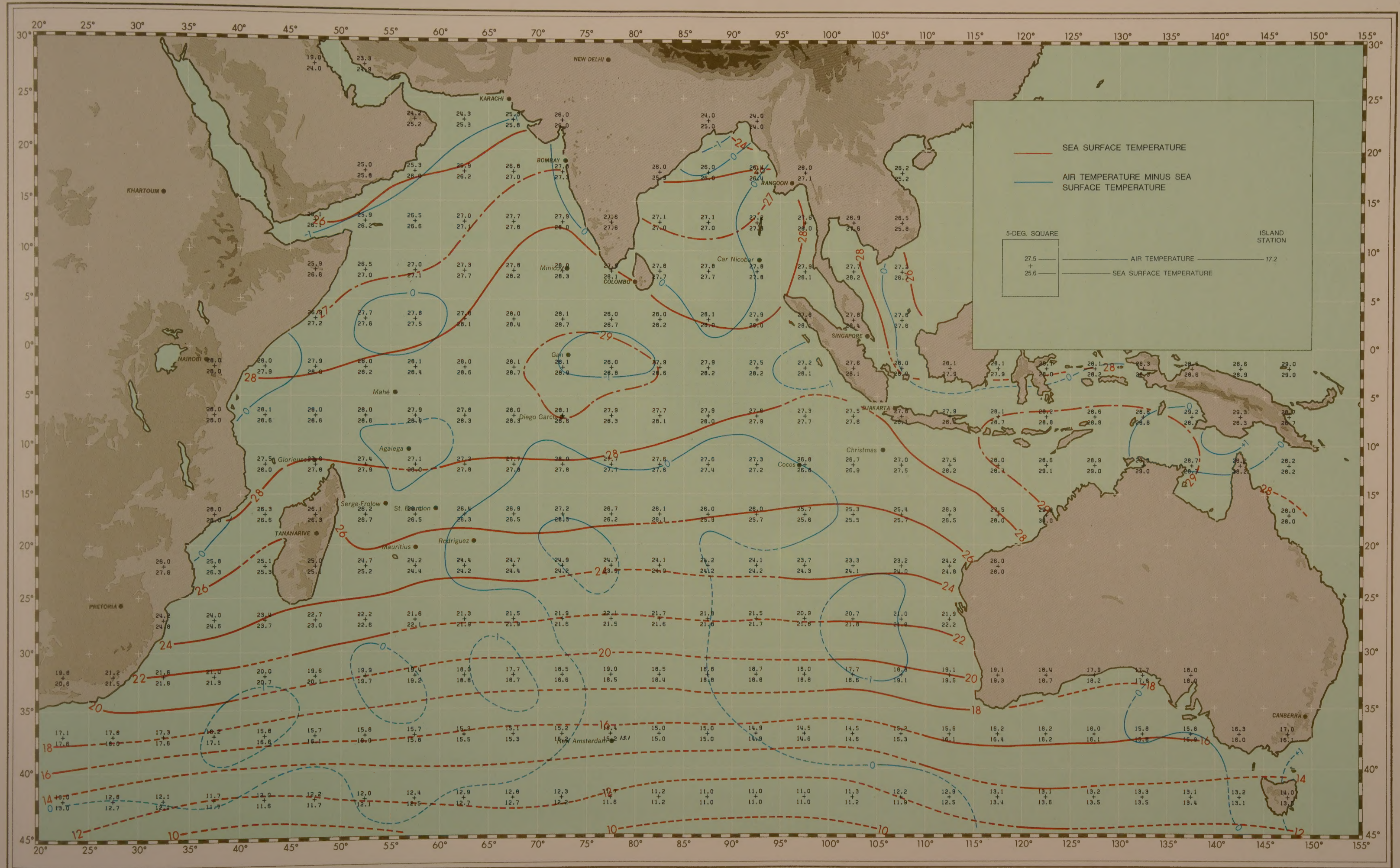


# AIR AND SEA SURFACE TEMPERATURES IN °C November 1963 Chart 59



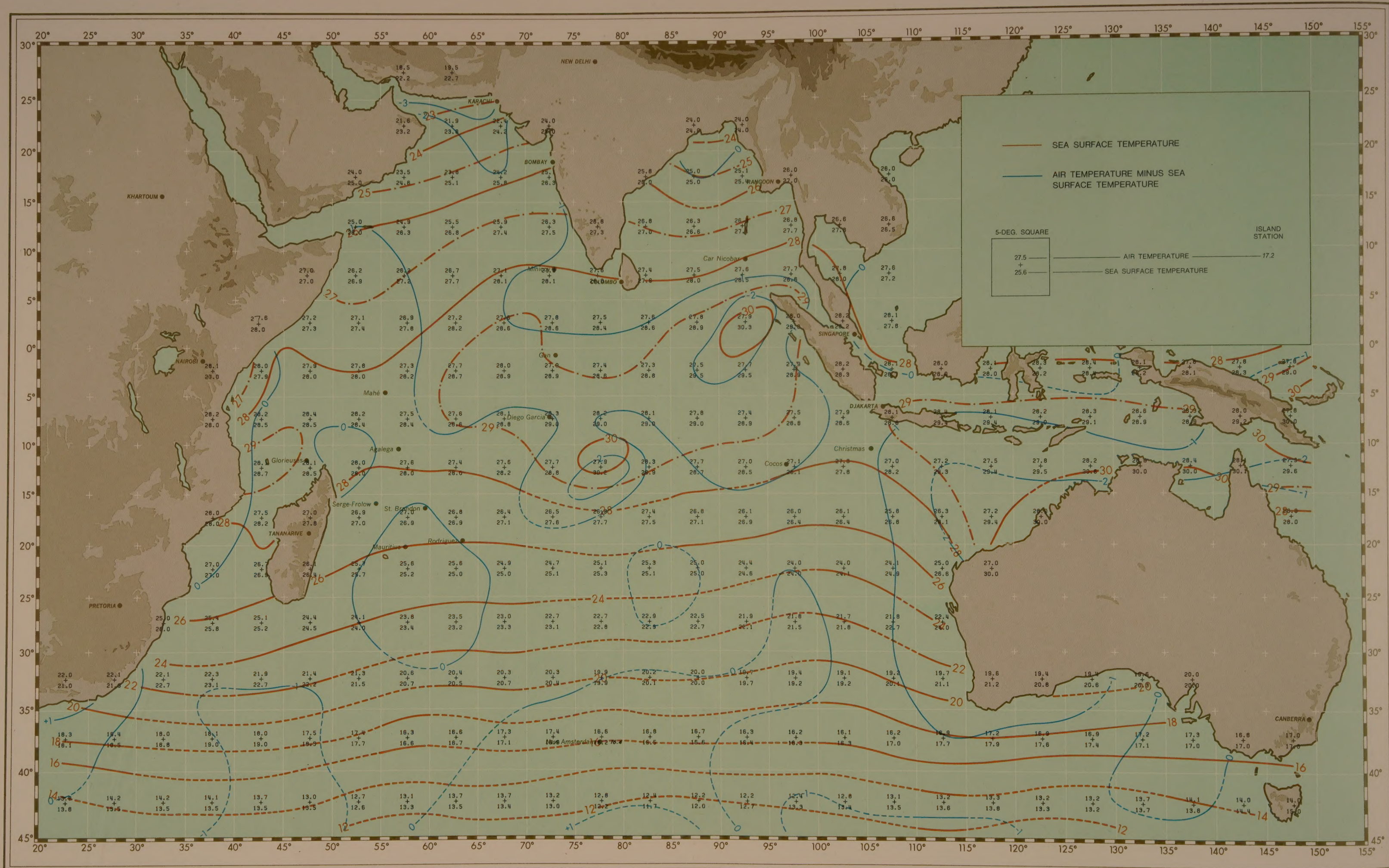


# AIR AND SEA SURFACE TEMPERATURES IN °C December 1963 Chart 60



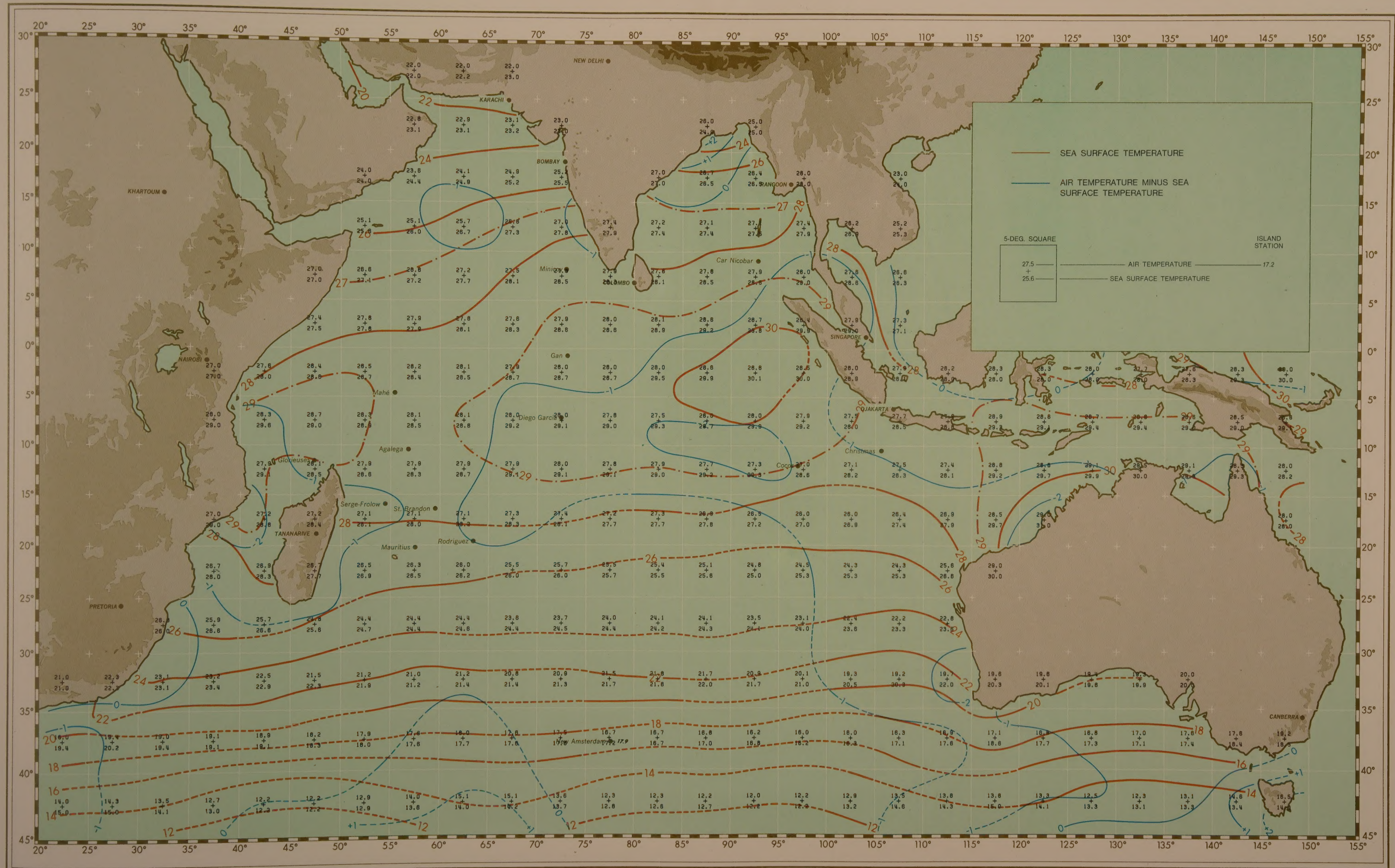


# AIR AND SEA SURFACE TEMPERATURES IN °C January 1964 Chart 61



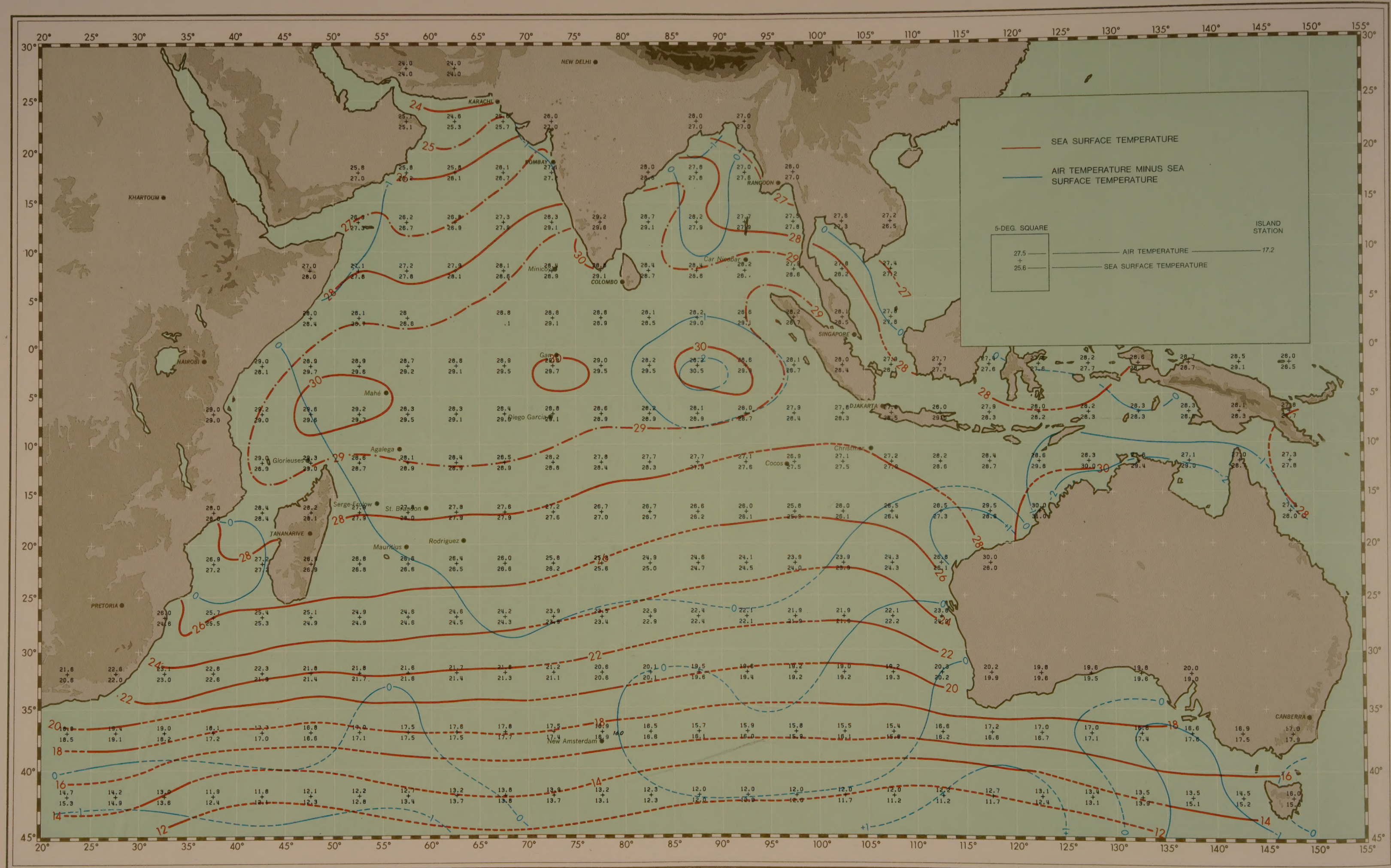


# AIR AND SEA SURFACE TEMPERATURES IN °C February 1964 Chart 62



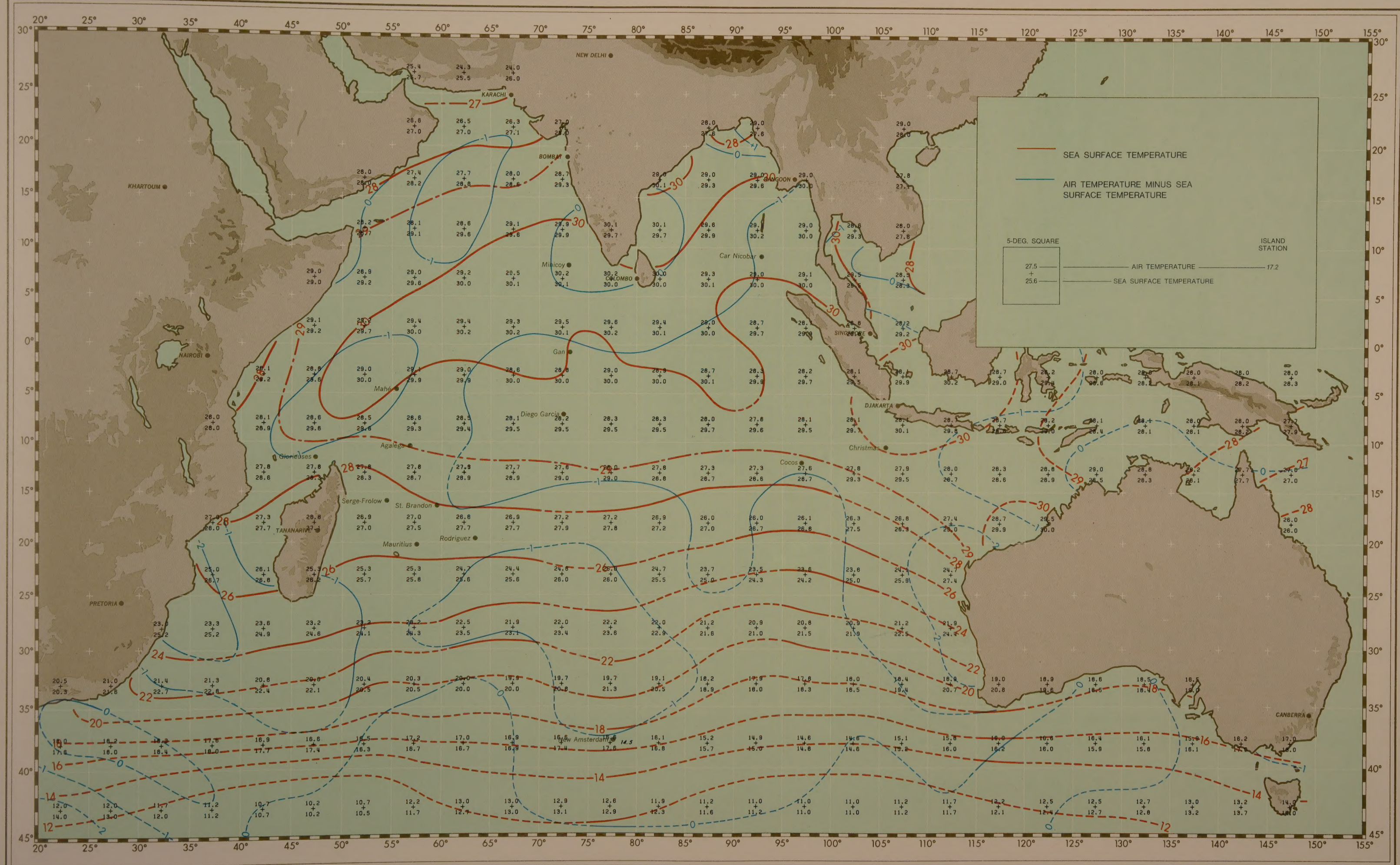


# AIR AND SEA SURFACE TEMPERATURES IN °C March 1964 Chart 63



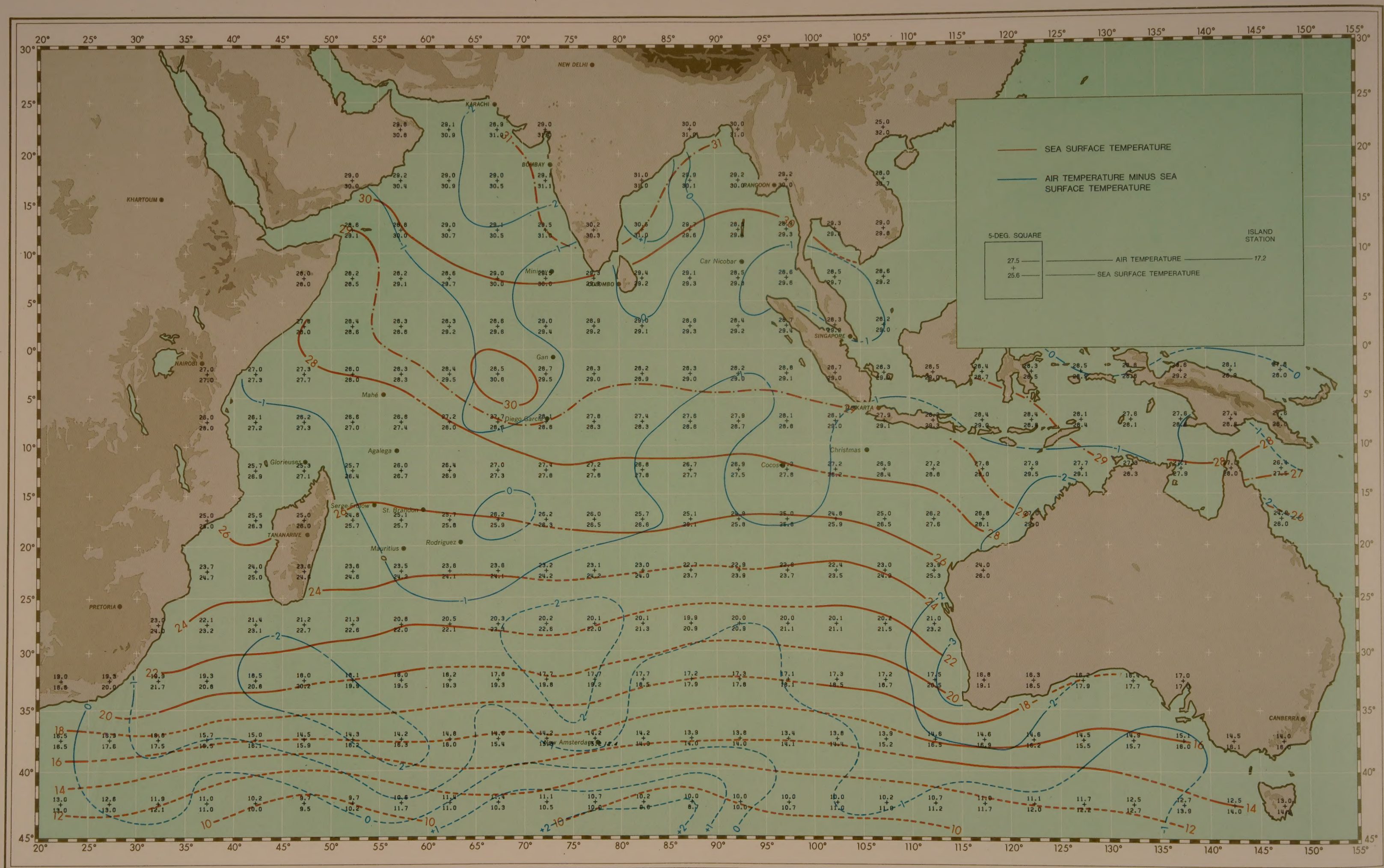


# AIR AND SEA SURFACE TEMPERATURES IN °C April 1964 Chart 64



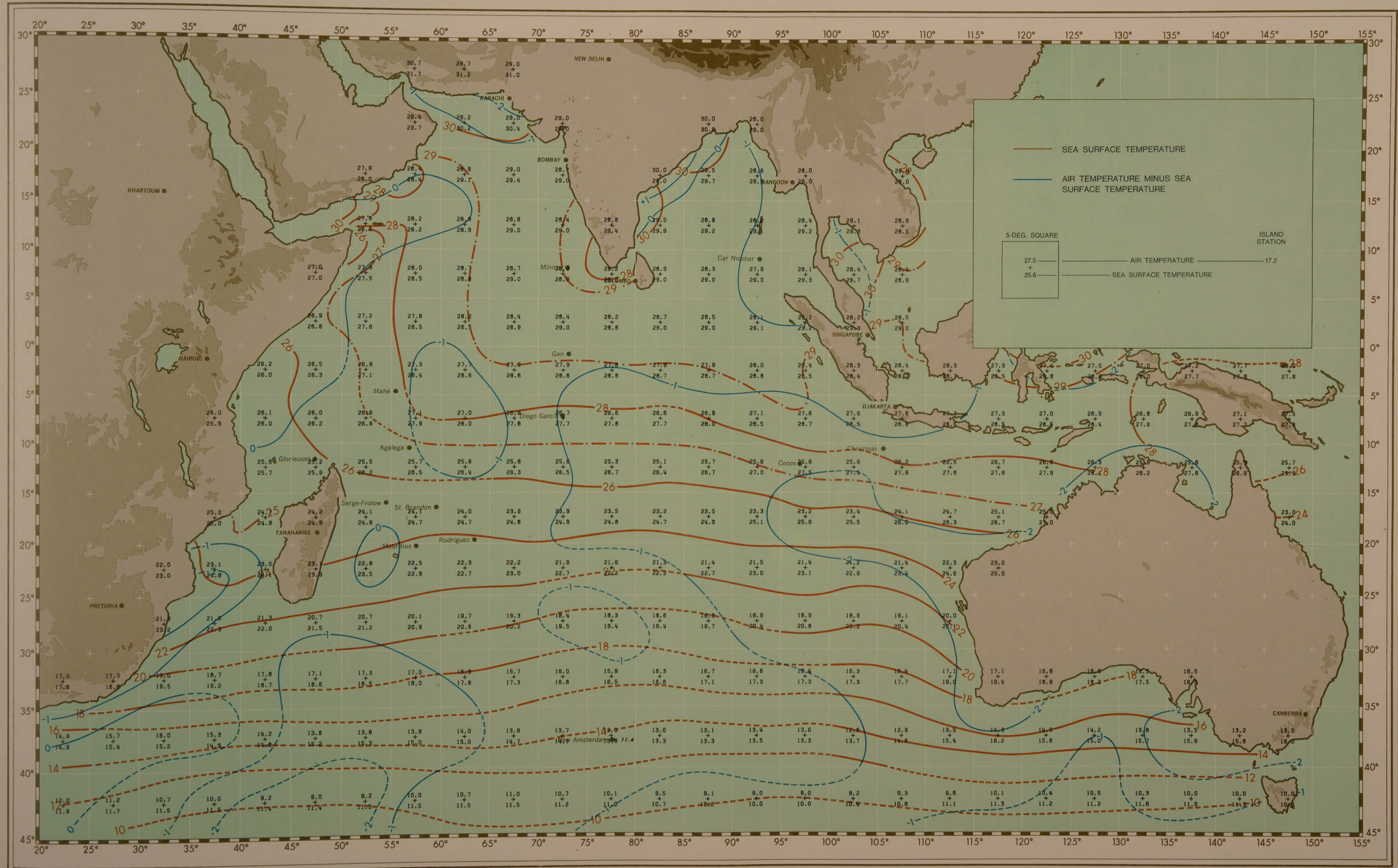


# AIR AND SEA SURFACE TEMPERATURES IN °C May 1964 Chart 65



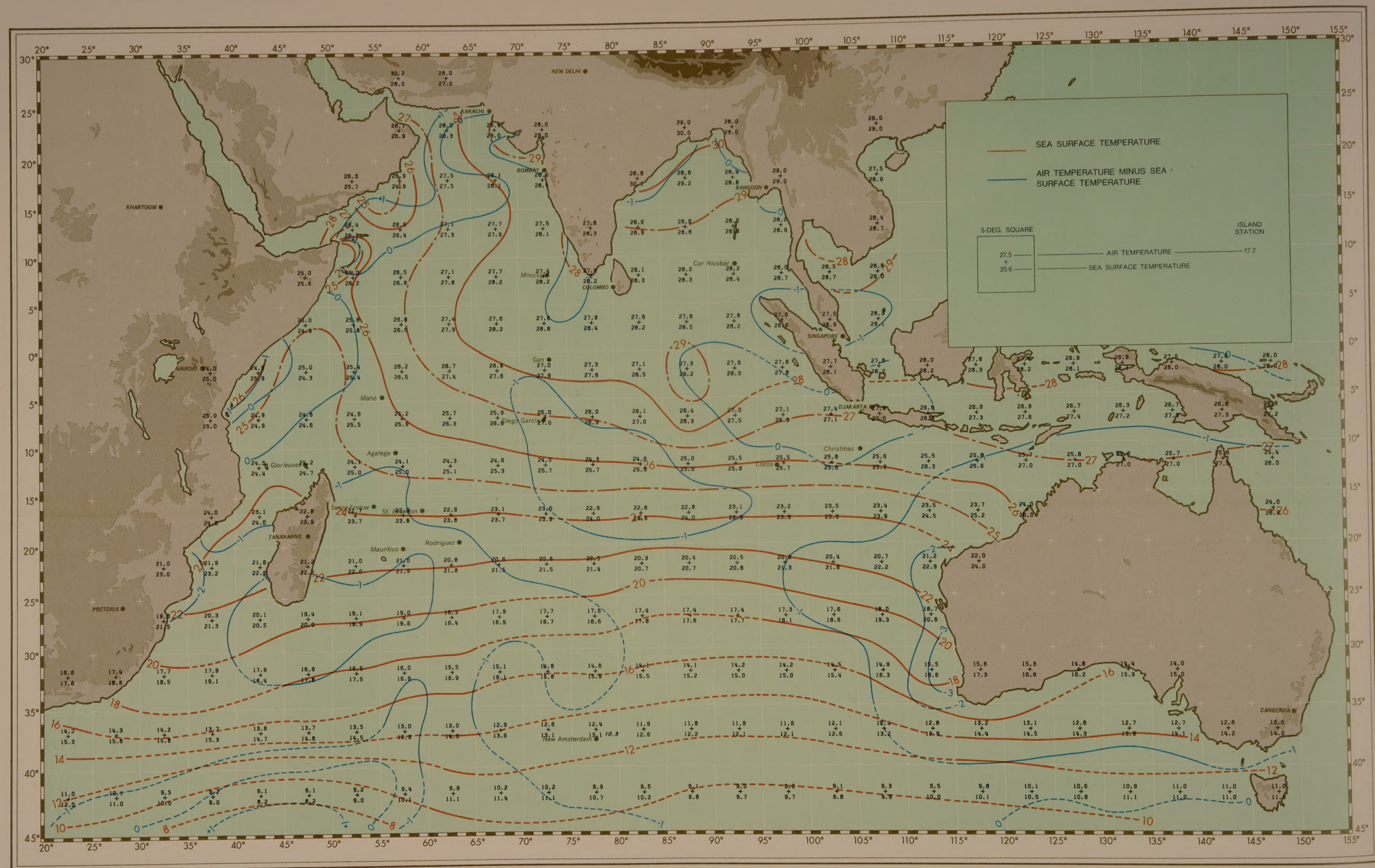


# AIR AND SEA SURFACE TEMPERATURES IN °C June 1964 Chart 66



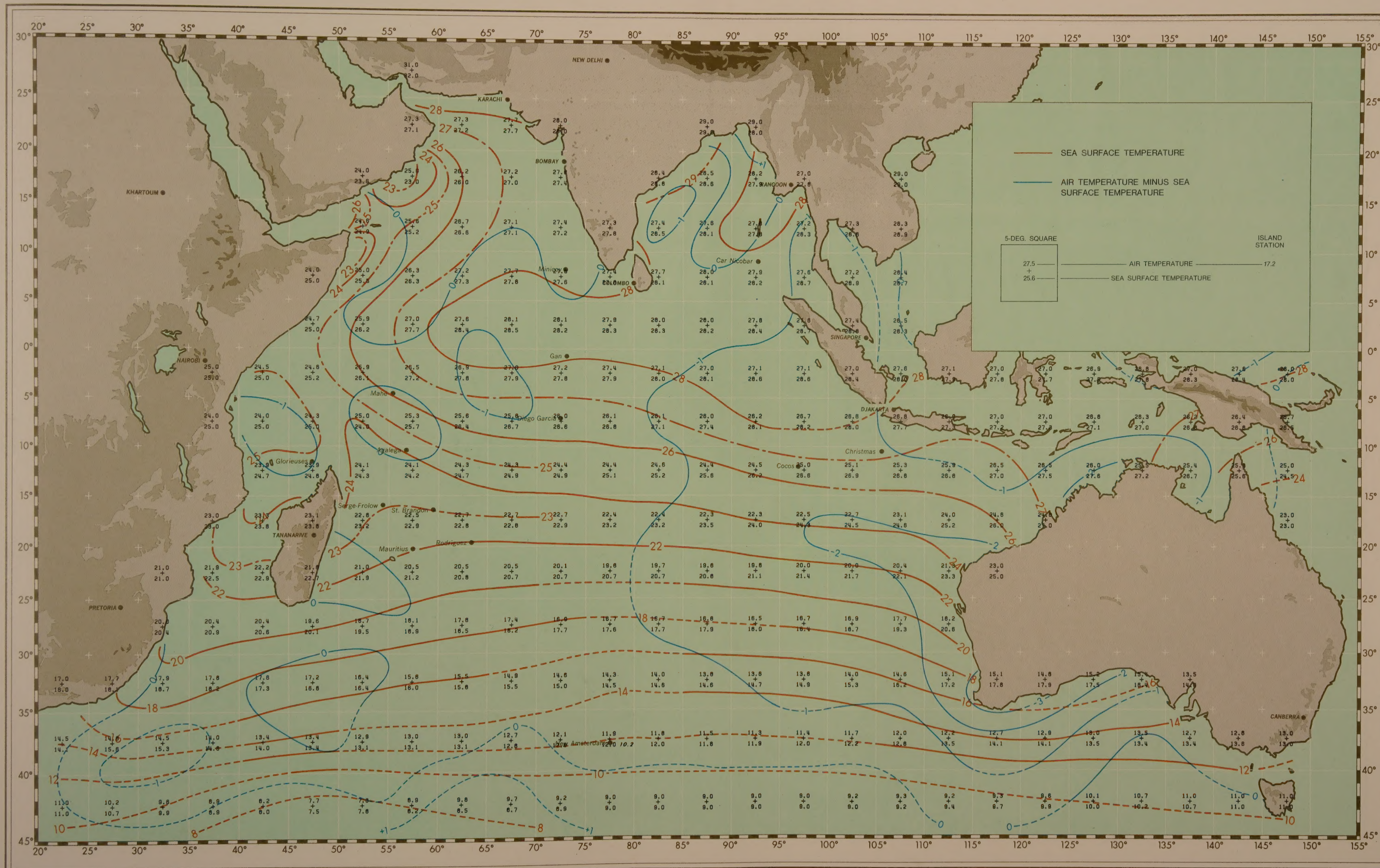


# AIR AND SEA SURFACE TEMPERATURES IN °C July 1964 Chart 67



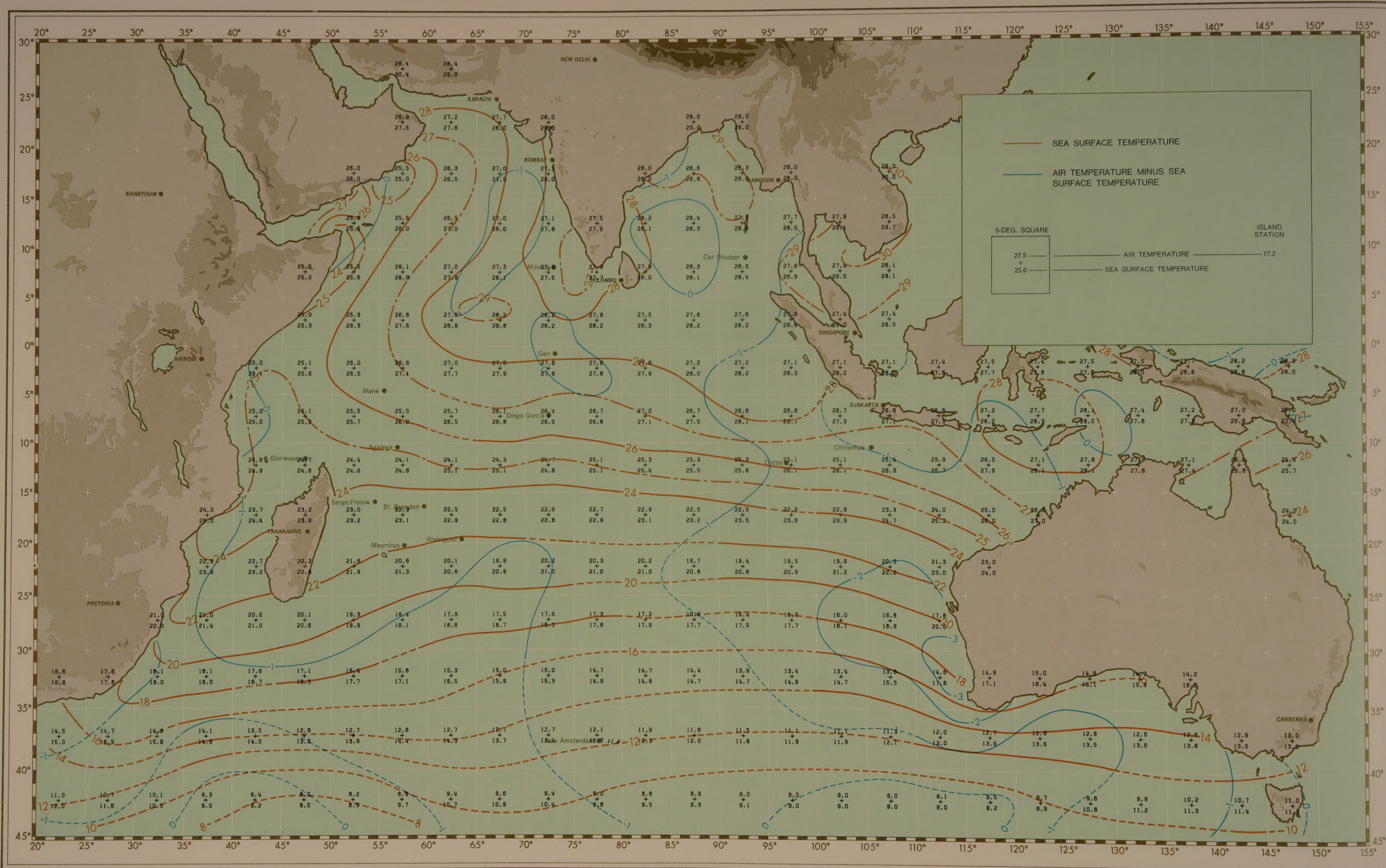


### Chart 68



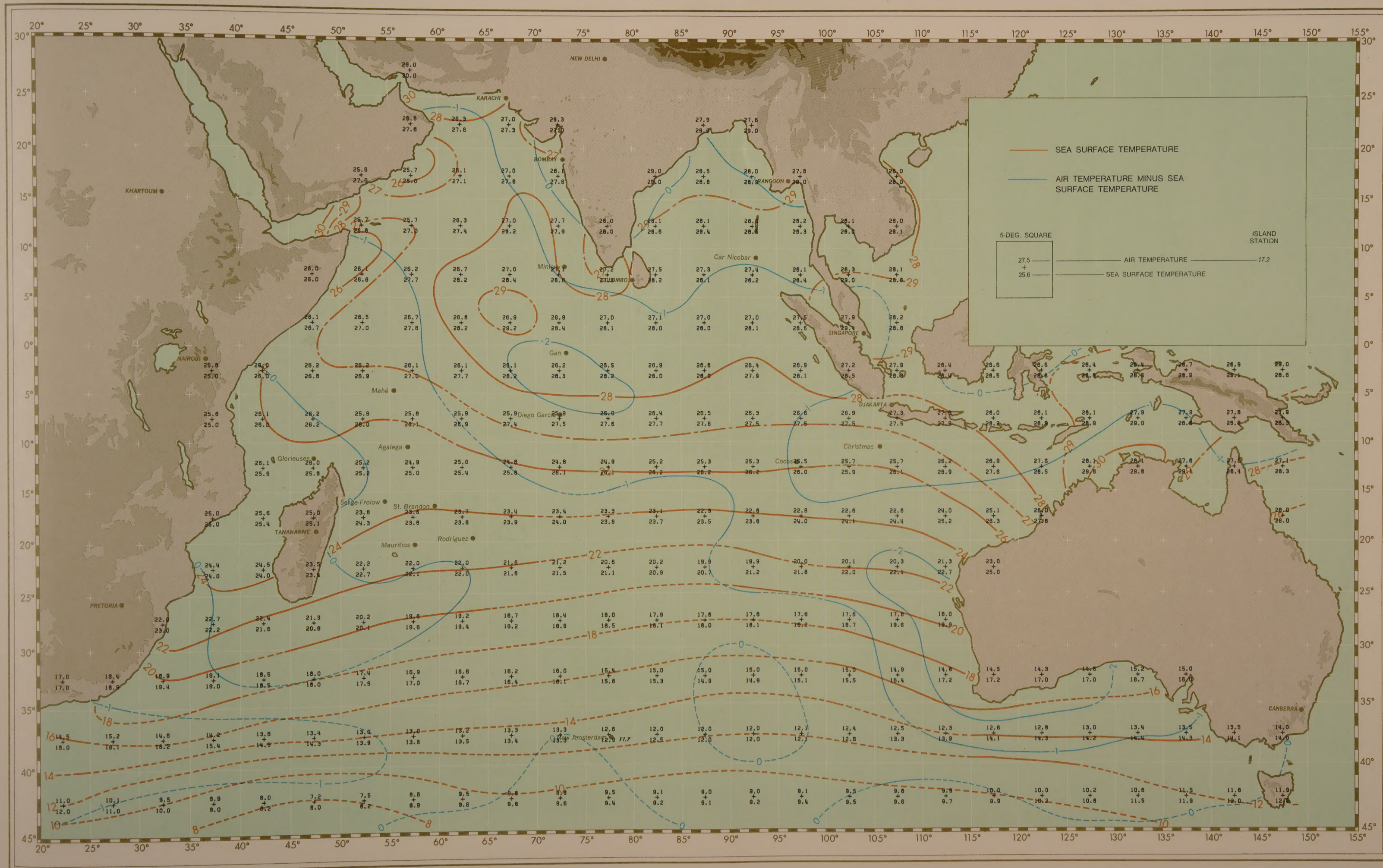


**AIR AND SEA SURFACE TEMPERATURES IN °C**    **September 1964**    **Chart 69**



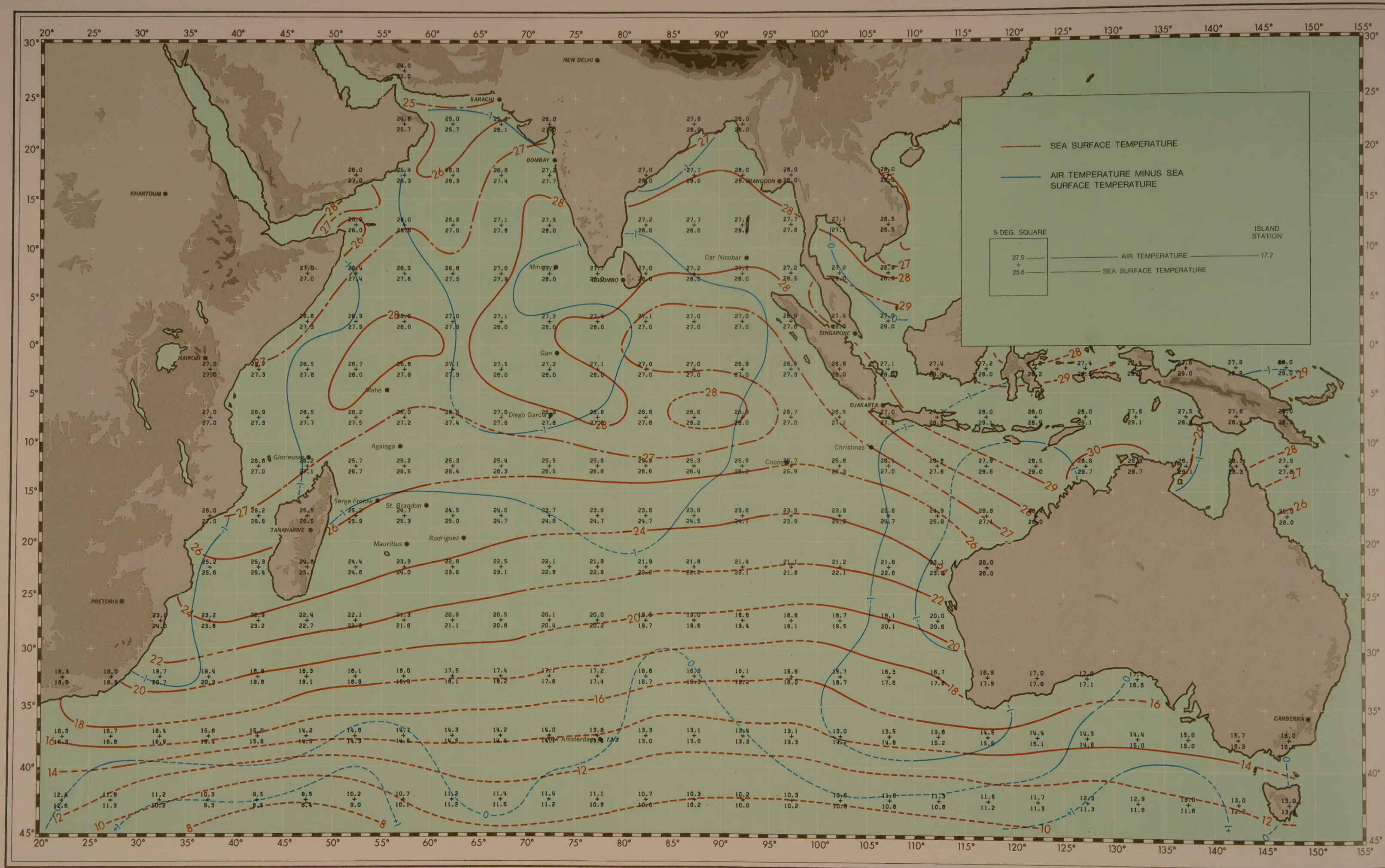


# AIR AND SEA SURFACE TEMPERATURES IN °C    October 1964    Chart 70



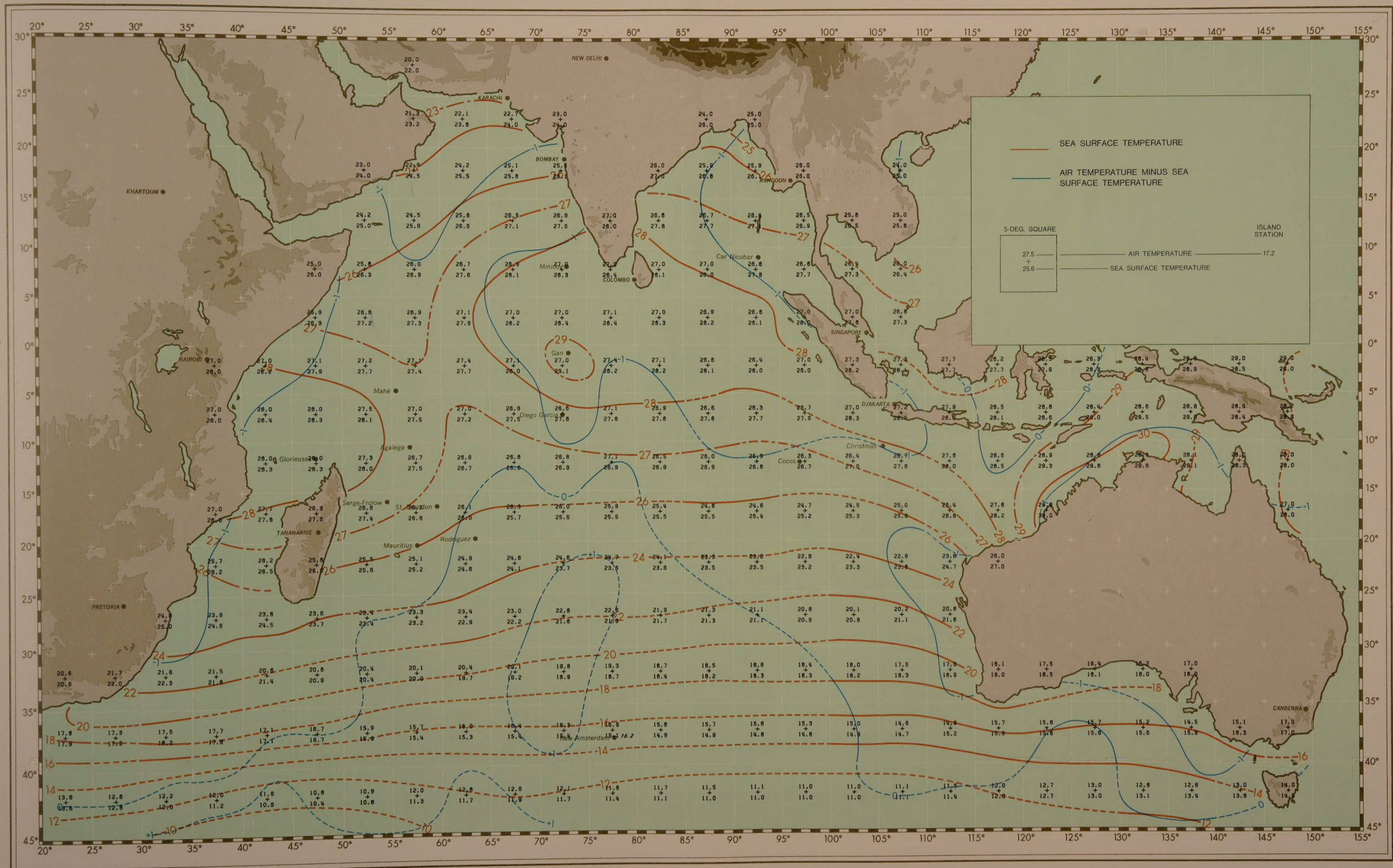


### Chart 71

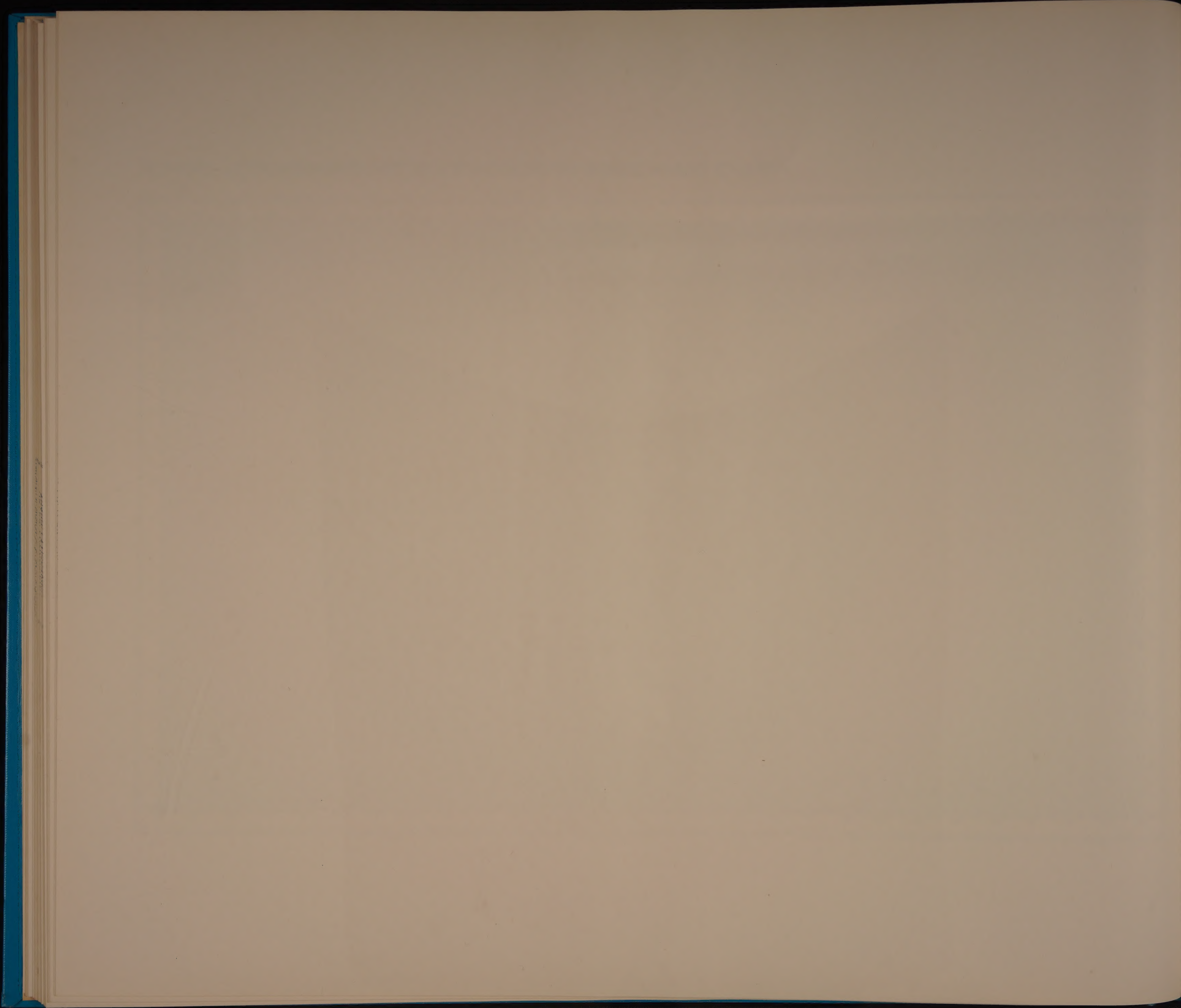




# AIR AND SEA SURFACE TEMPERATURES IN °C December 1964 Chart 72





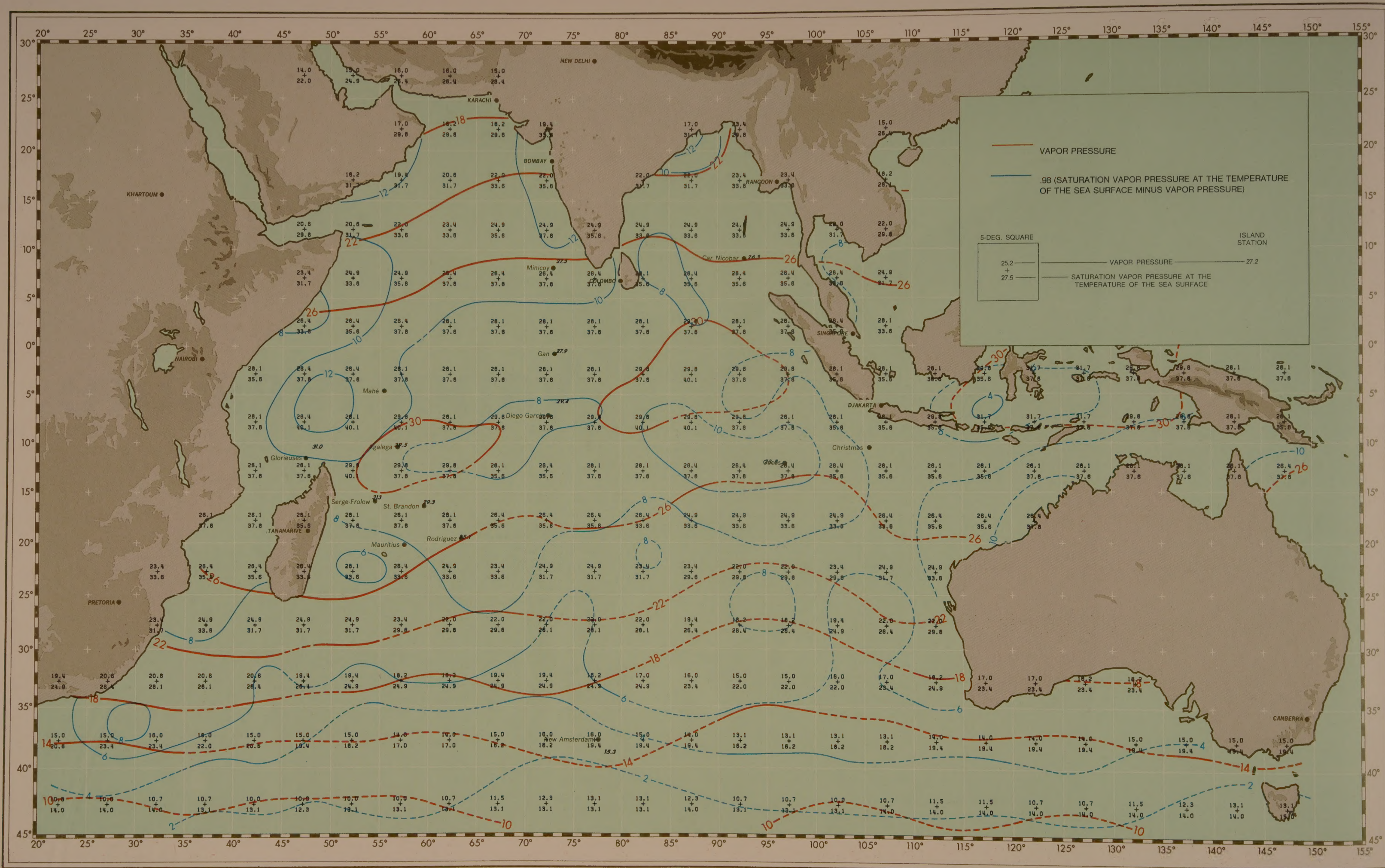




# Vapor Pressure

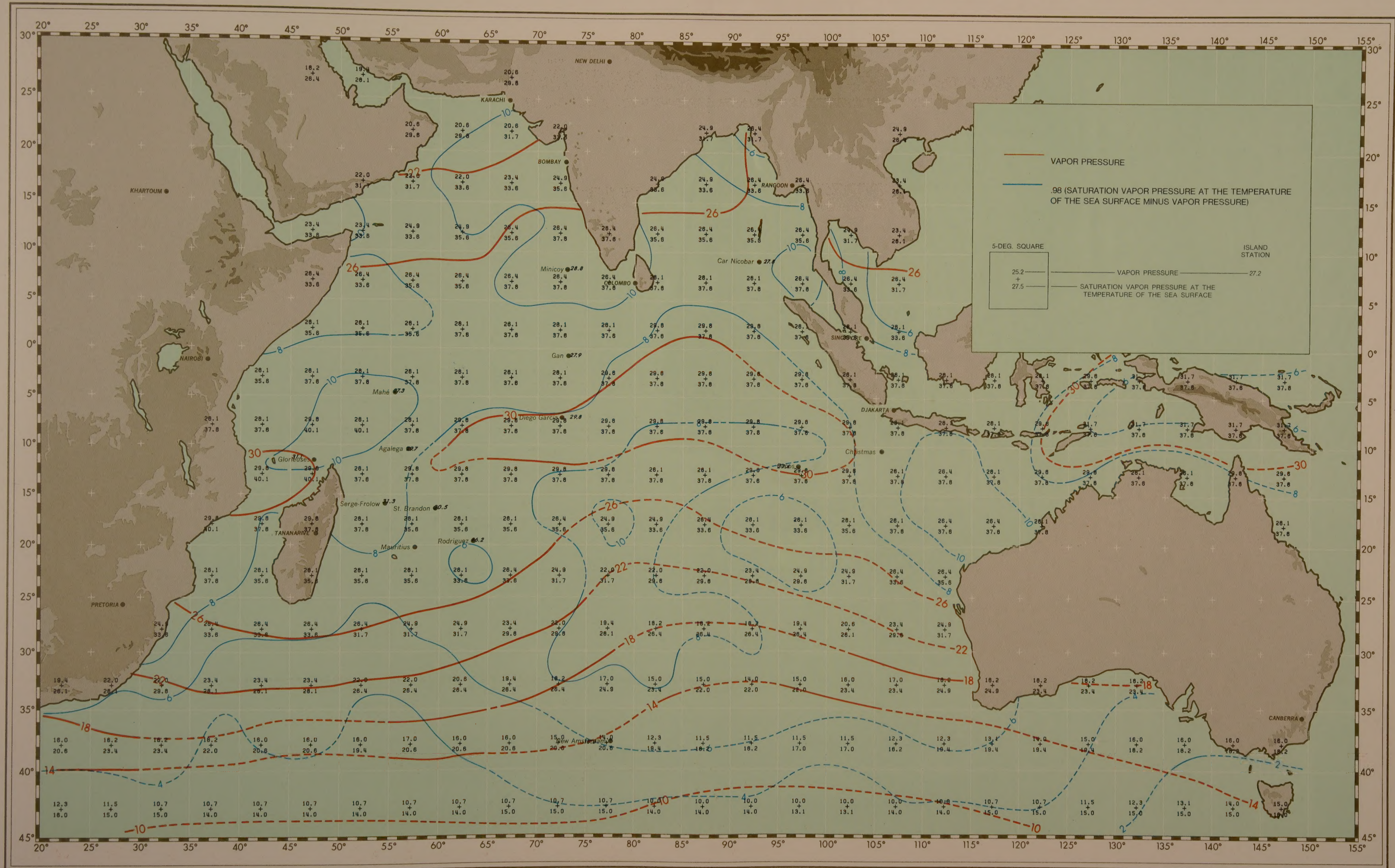


### Chart 73



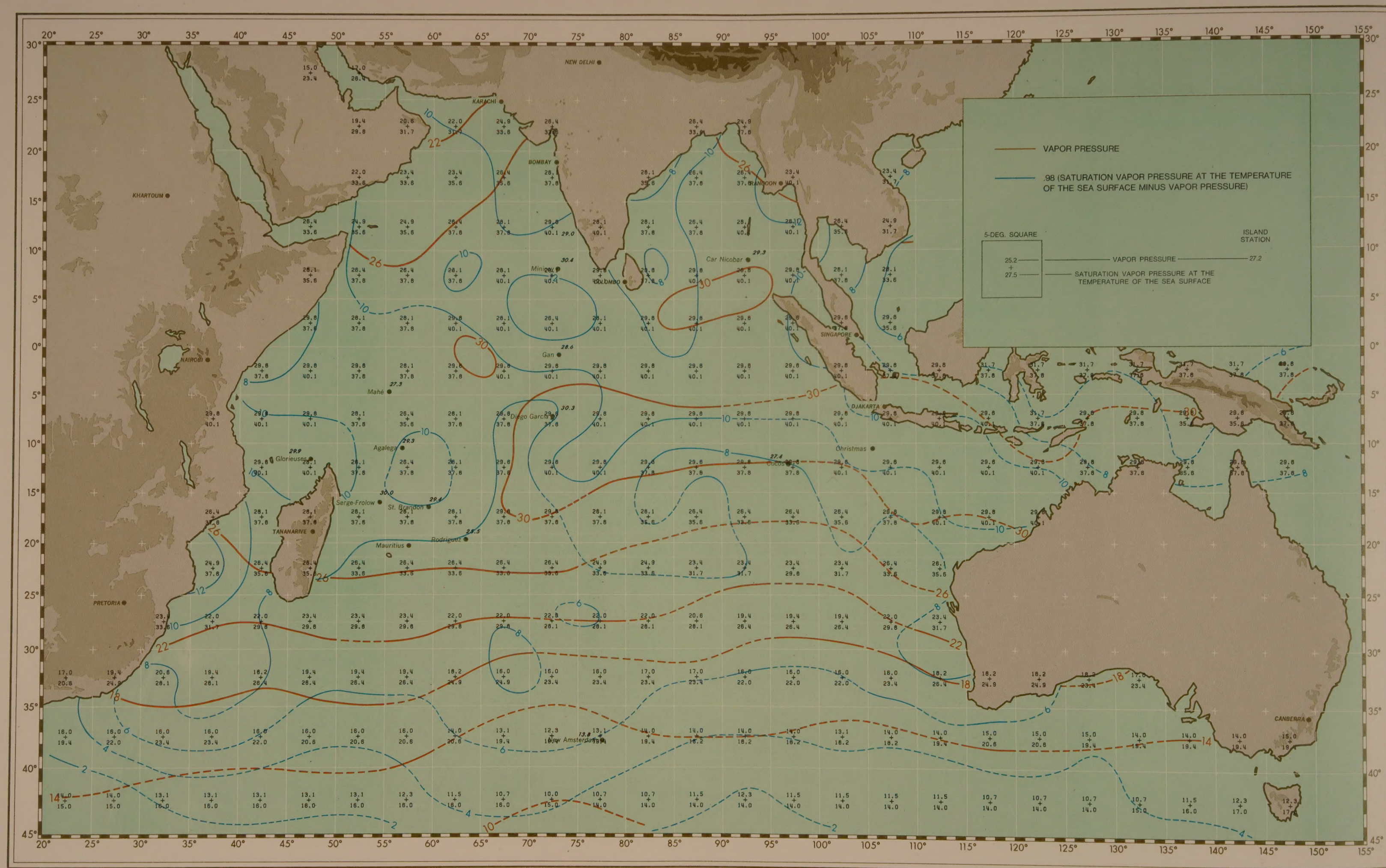


# VAPOR PRESSURE IN MILLIBARS February 1963 Chart 74



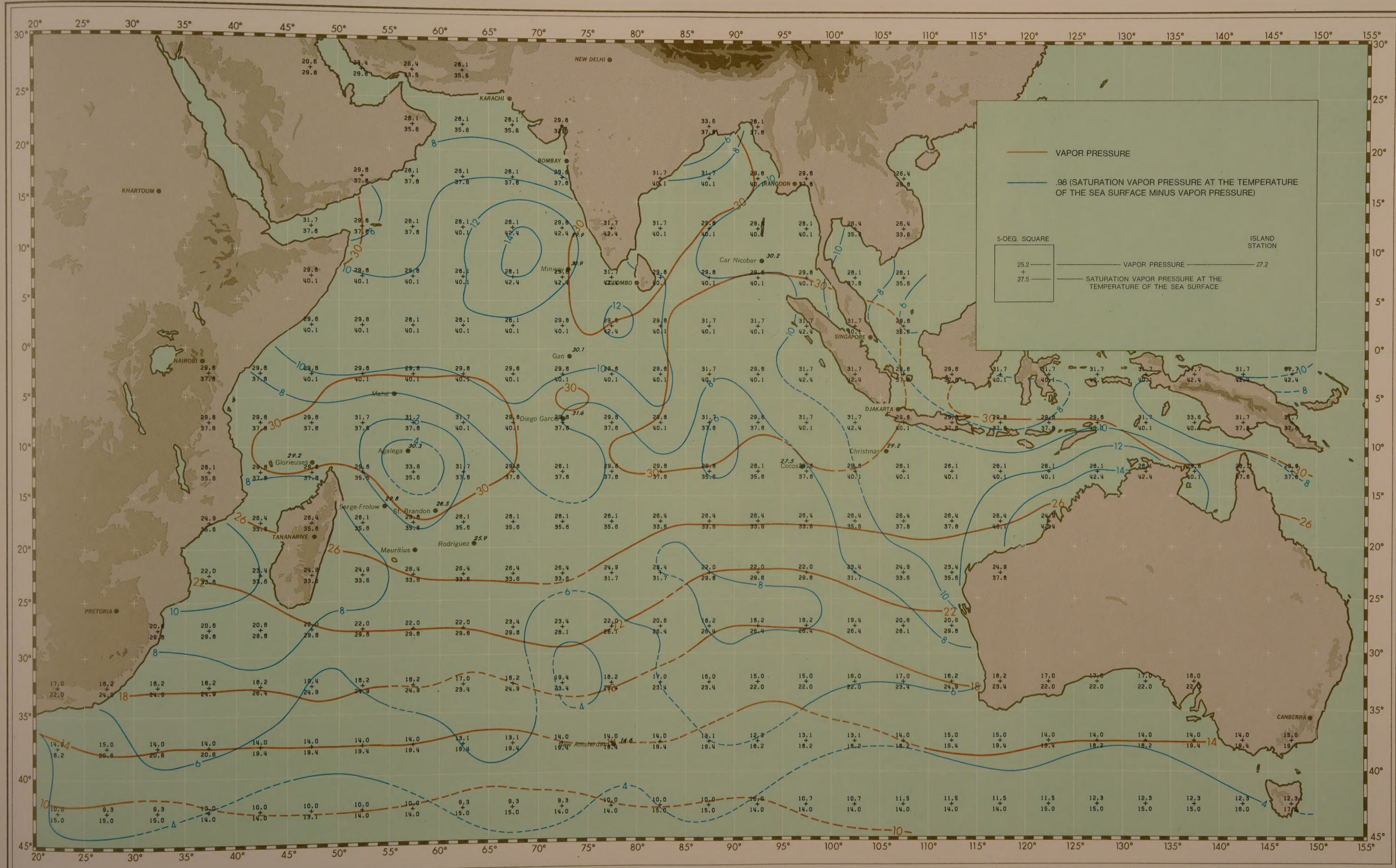


# VAPOR PRESSURE IN MILLIBARS March 1963 Chart 75



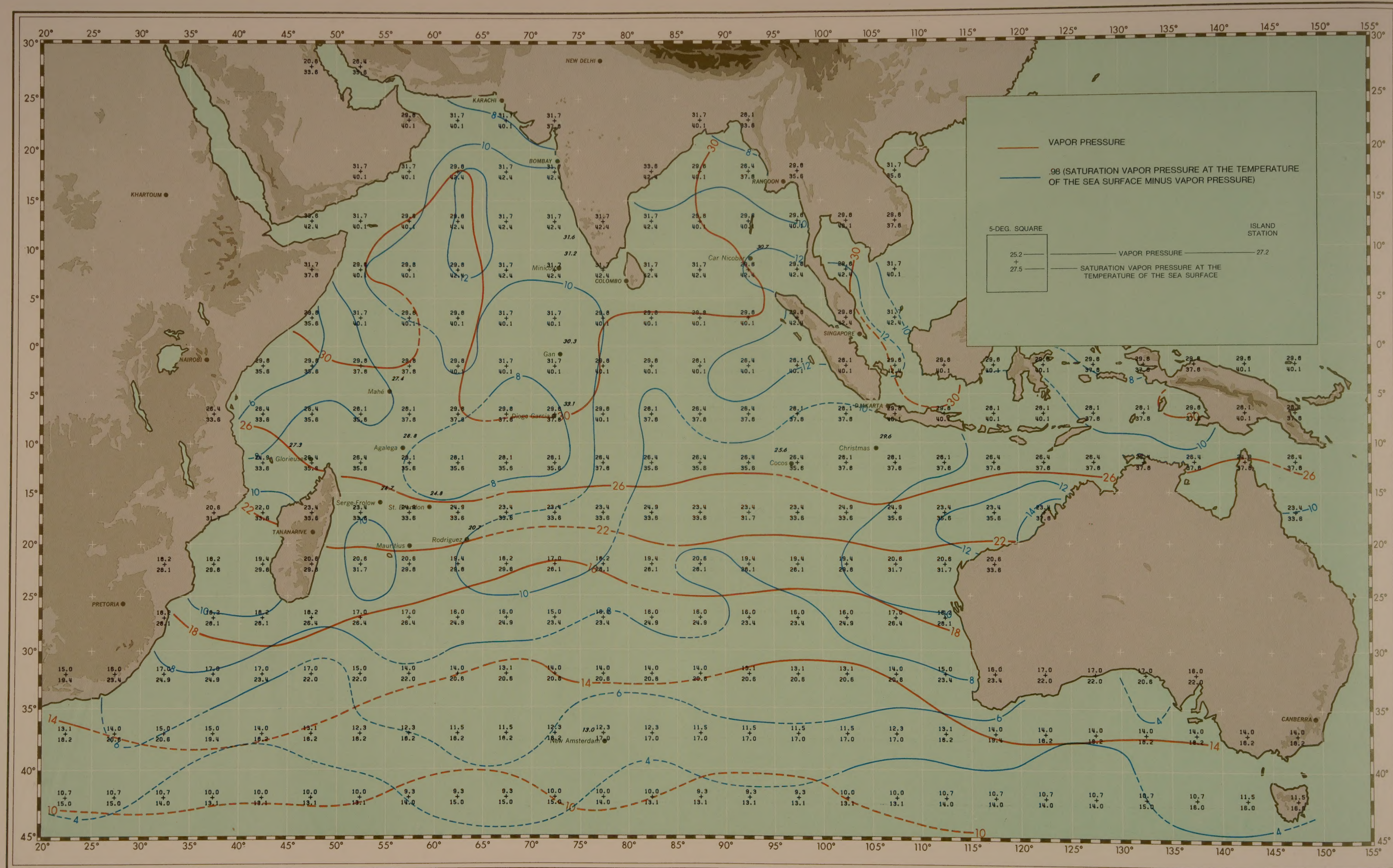


# VAPOR PRESSURE IN MILLIBARS April 1963 Chart 76



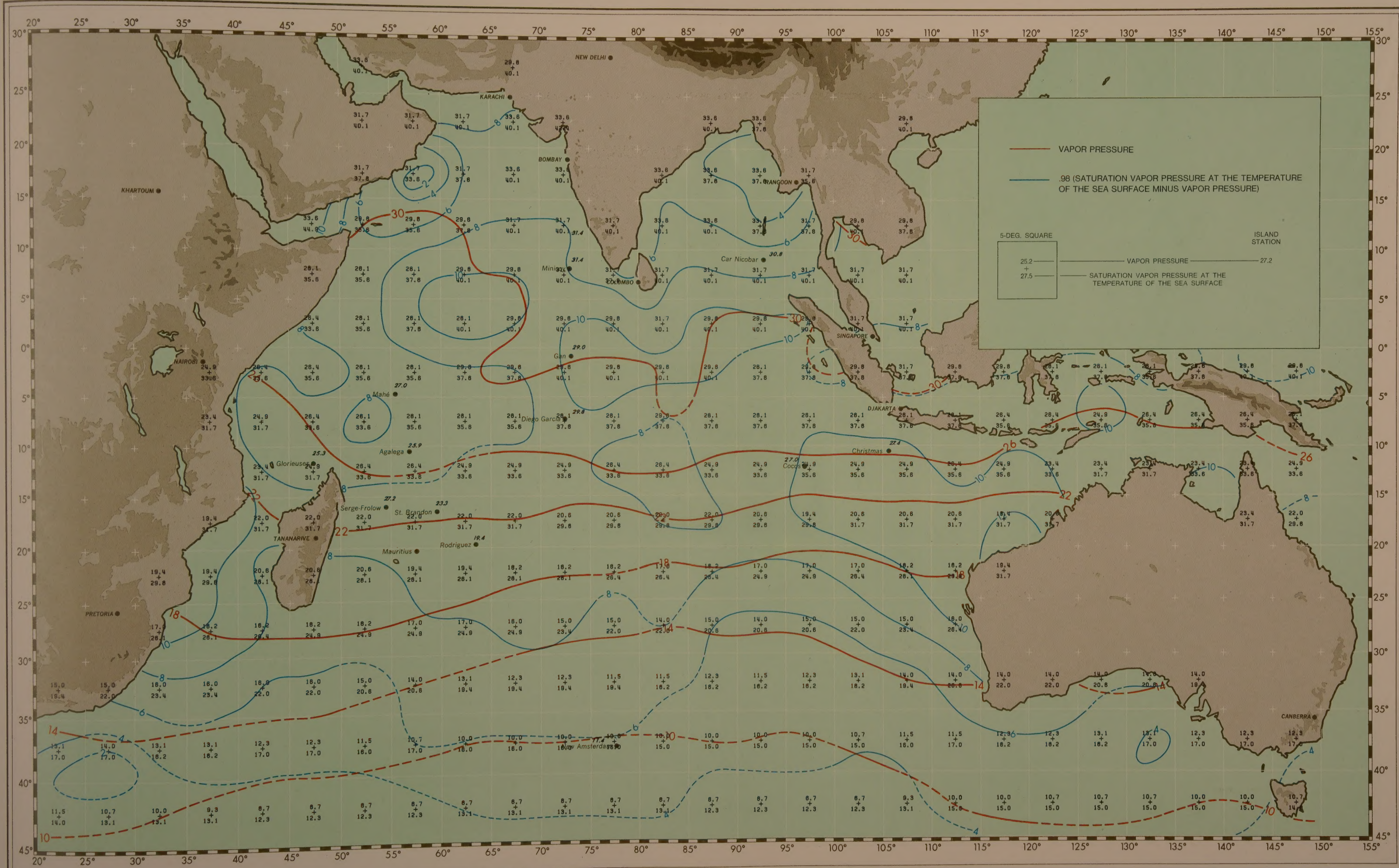


# VAPOR PRESSURE IN MILLIBARS May 1963 Chart 77



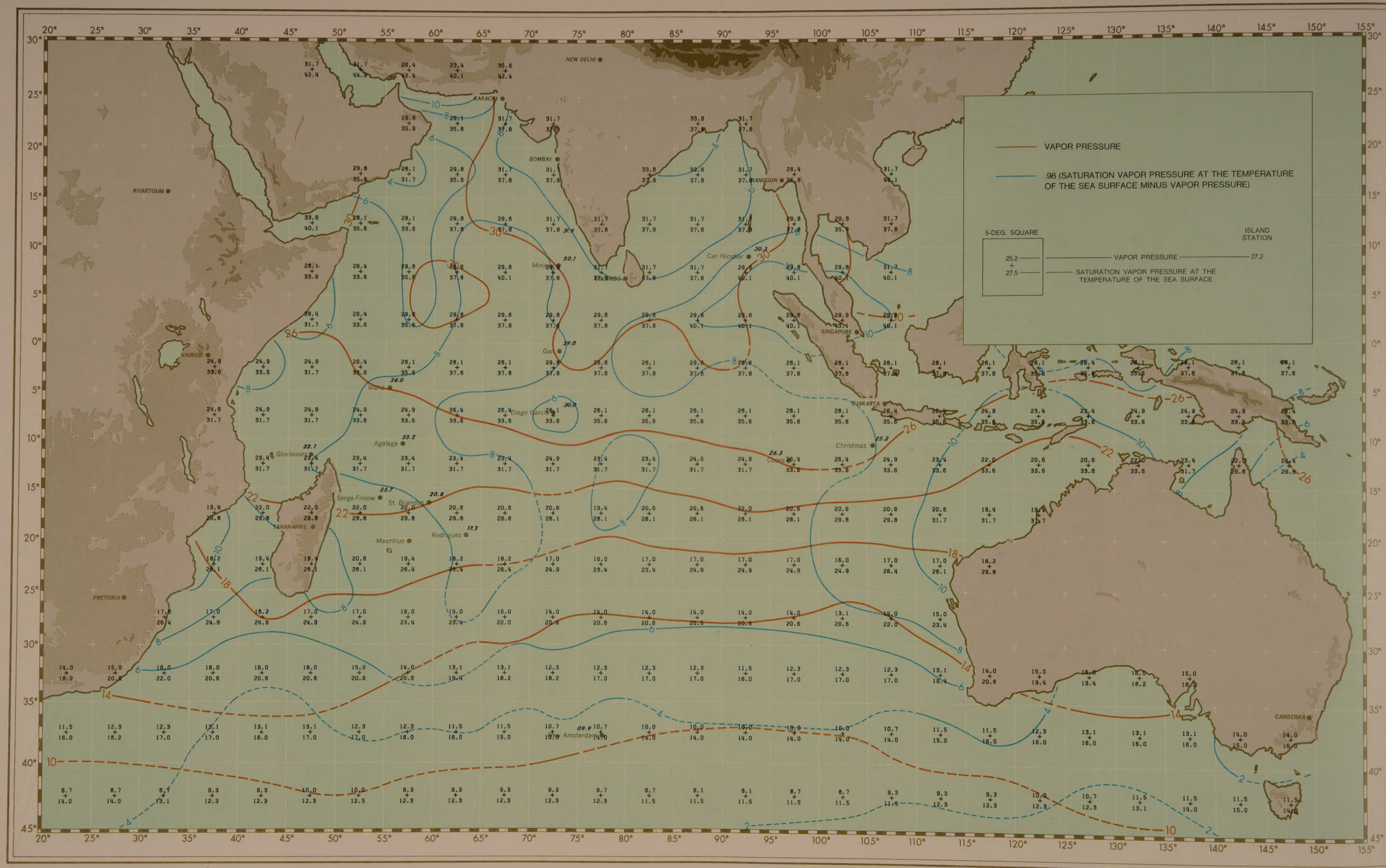


# VAPOR PRESSURE IN MILLIBARS June 1963 Chart 78



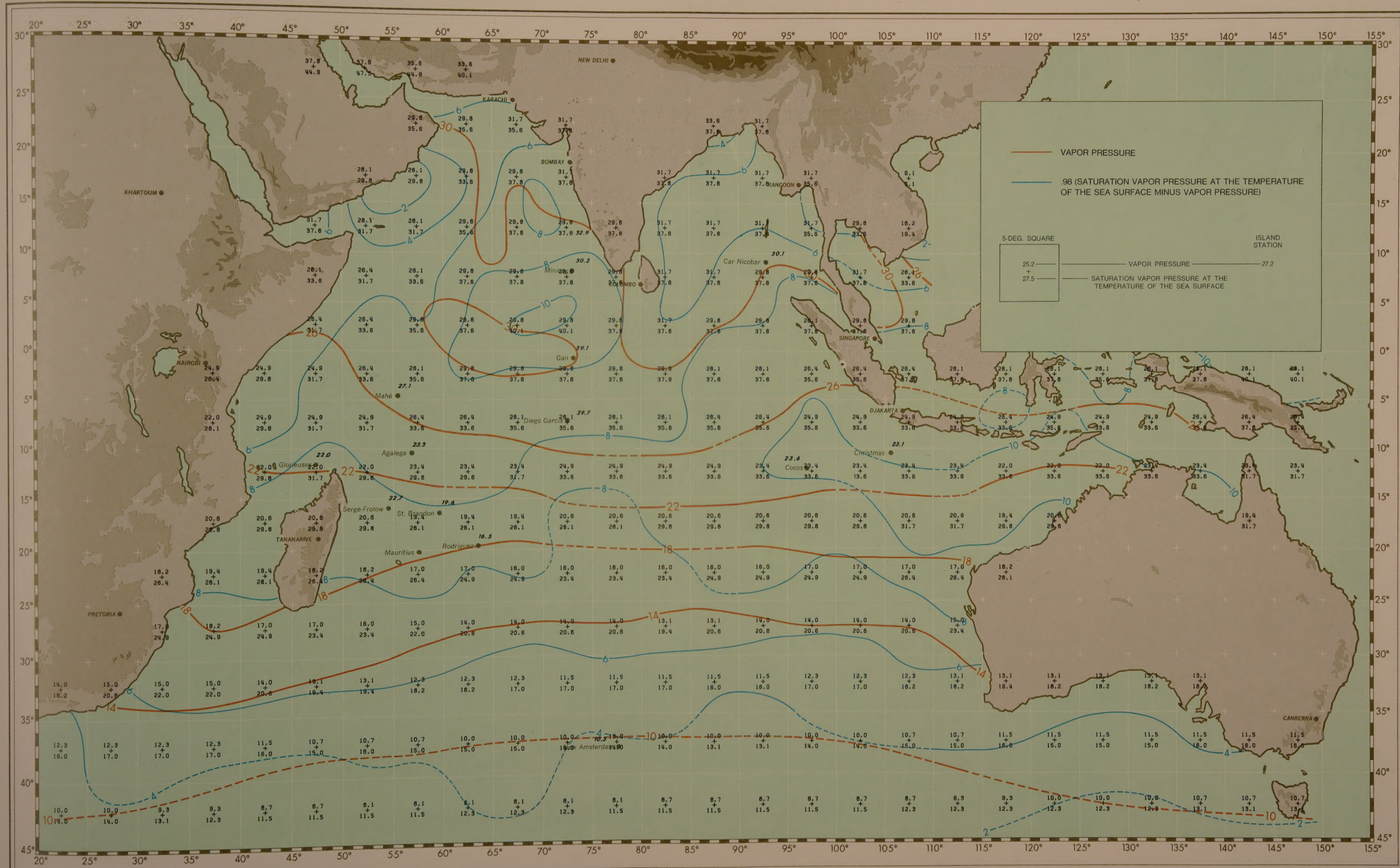


# VAPOR PRESSURE IN MILLIBARS July 1963 Chart 79



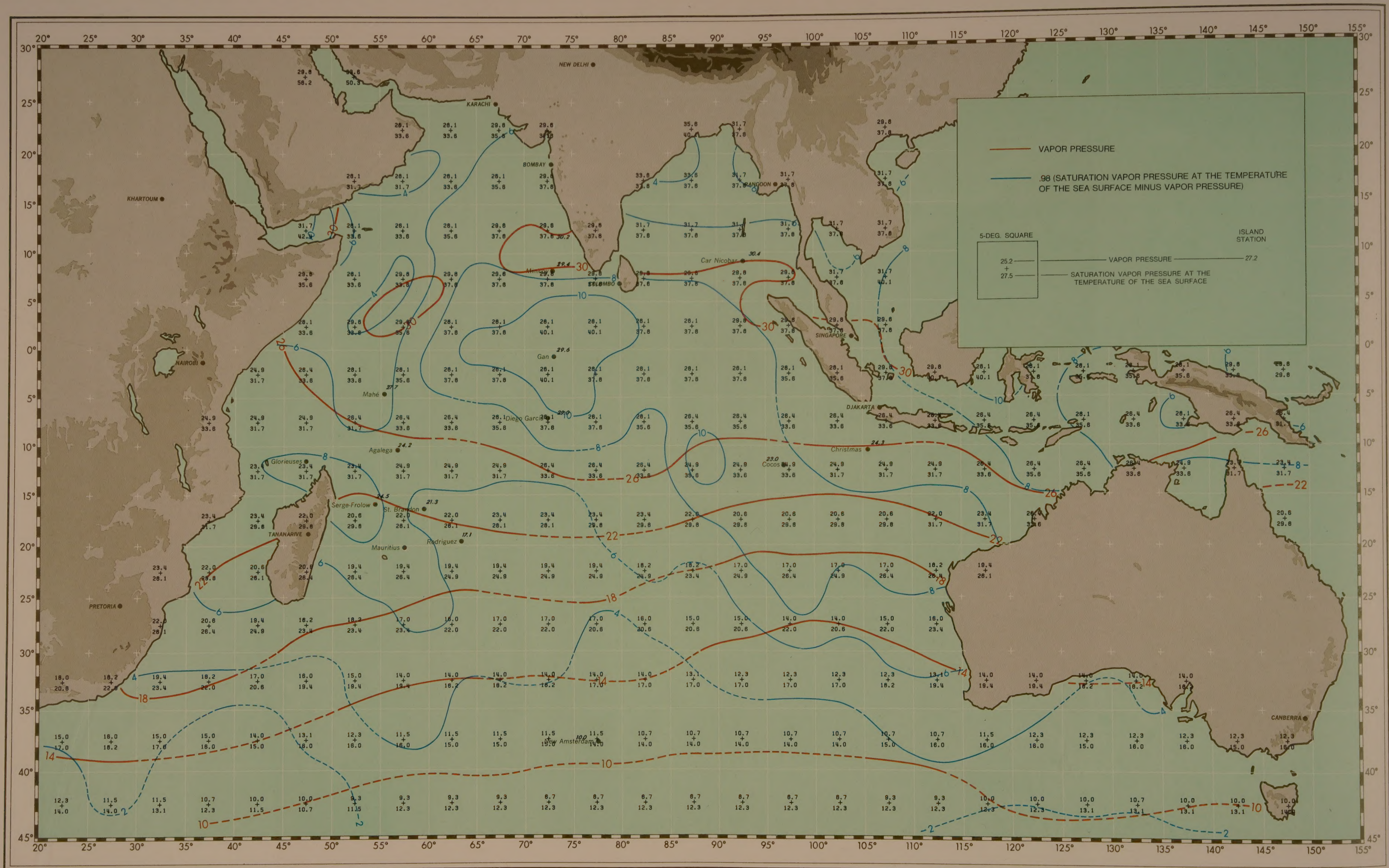


# VAPOR PRESSURE IN MILLIBARS August 1963 Chart 80



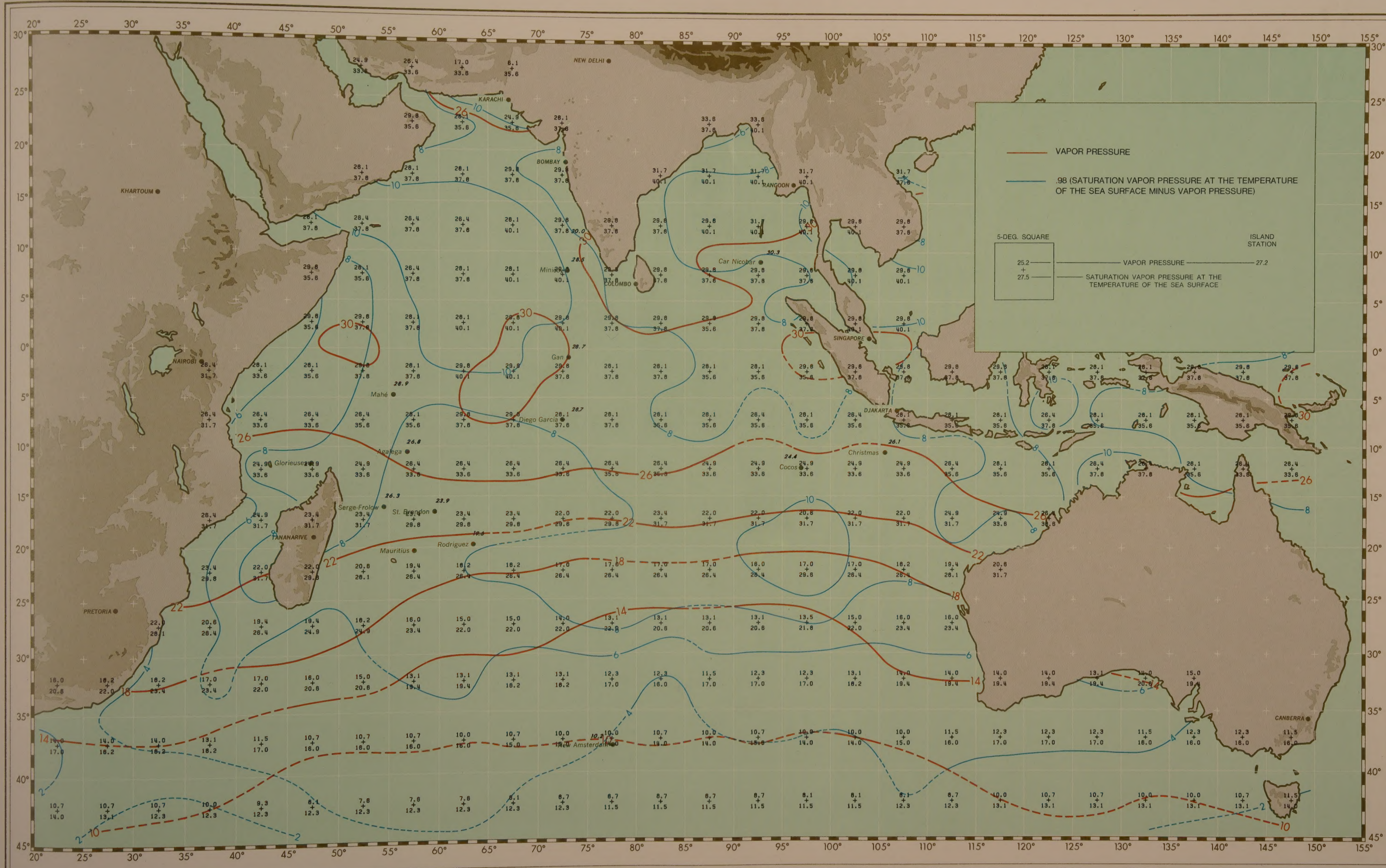


# VAPOR PRESSURE IN MILLIBARS September 1963 Chart 81



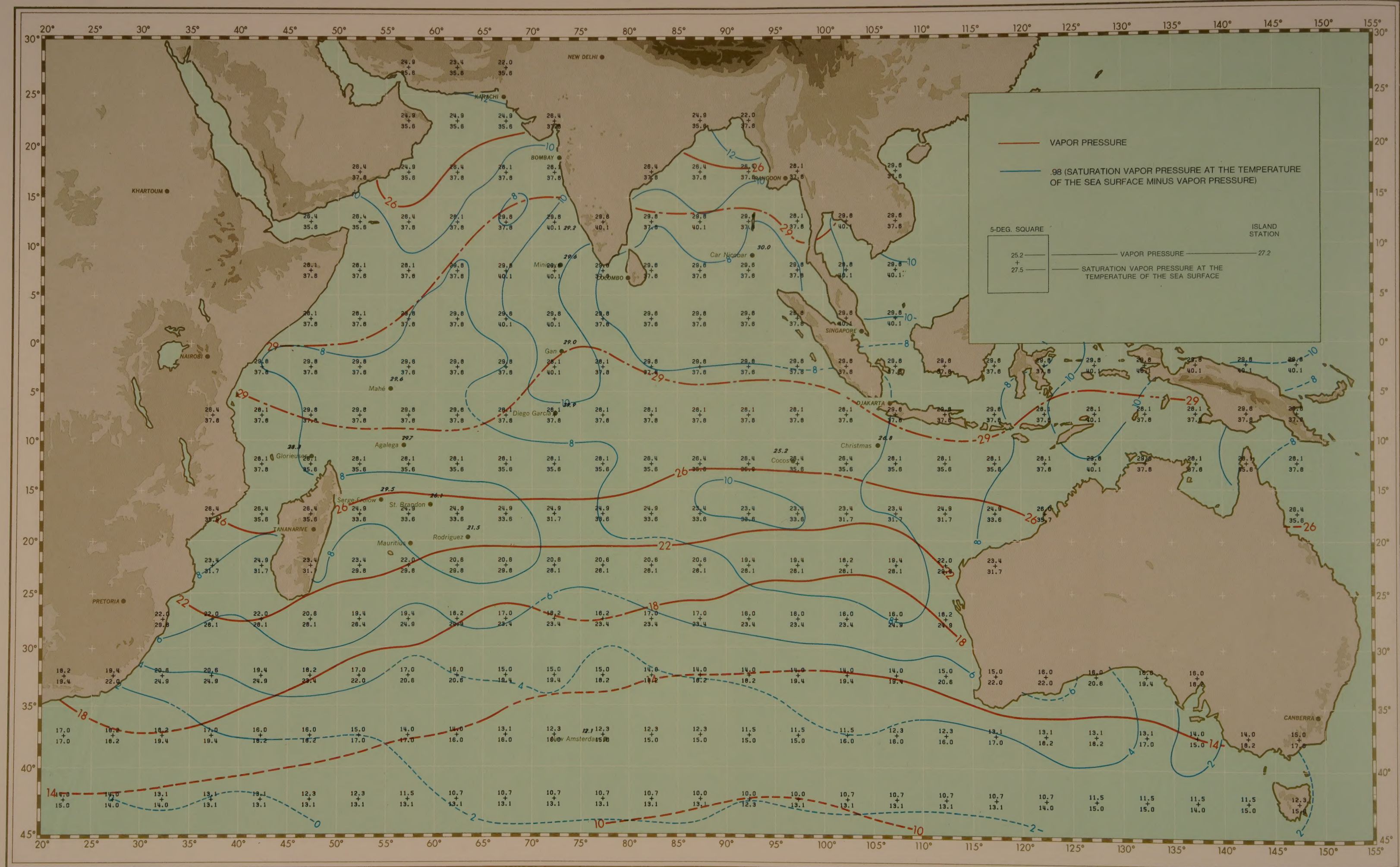


# VAPOR PRESSURE IN MILLIBARS    October 1963    Chart 82



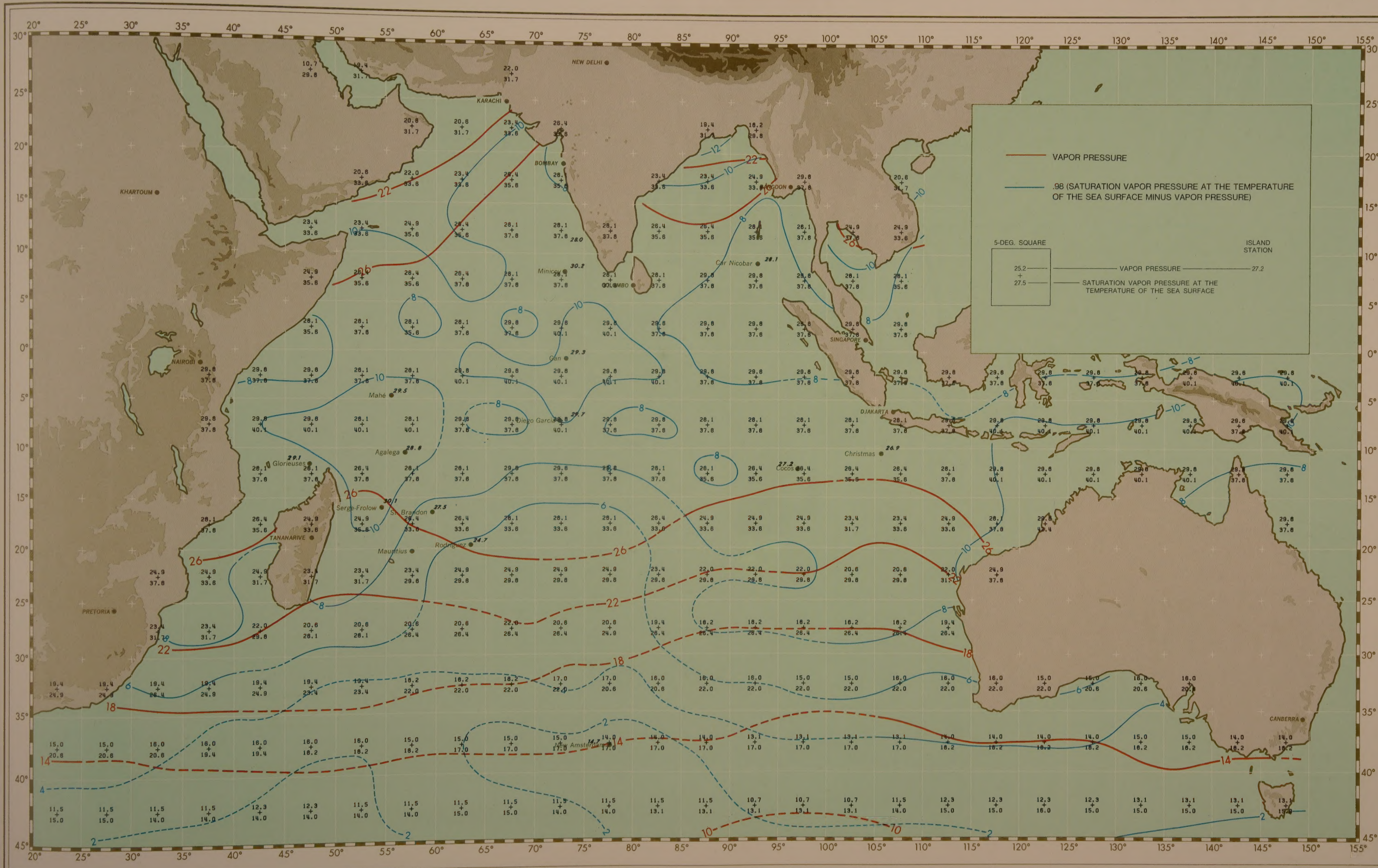


# VAPOR PRESSURE IN MILLIBARS November 1963 Chart 83



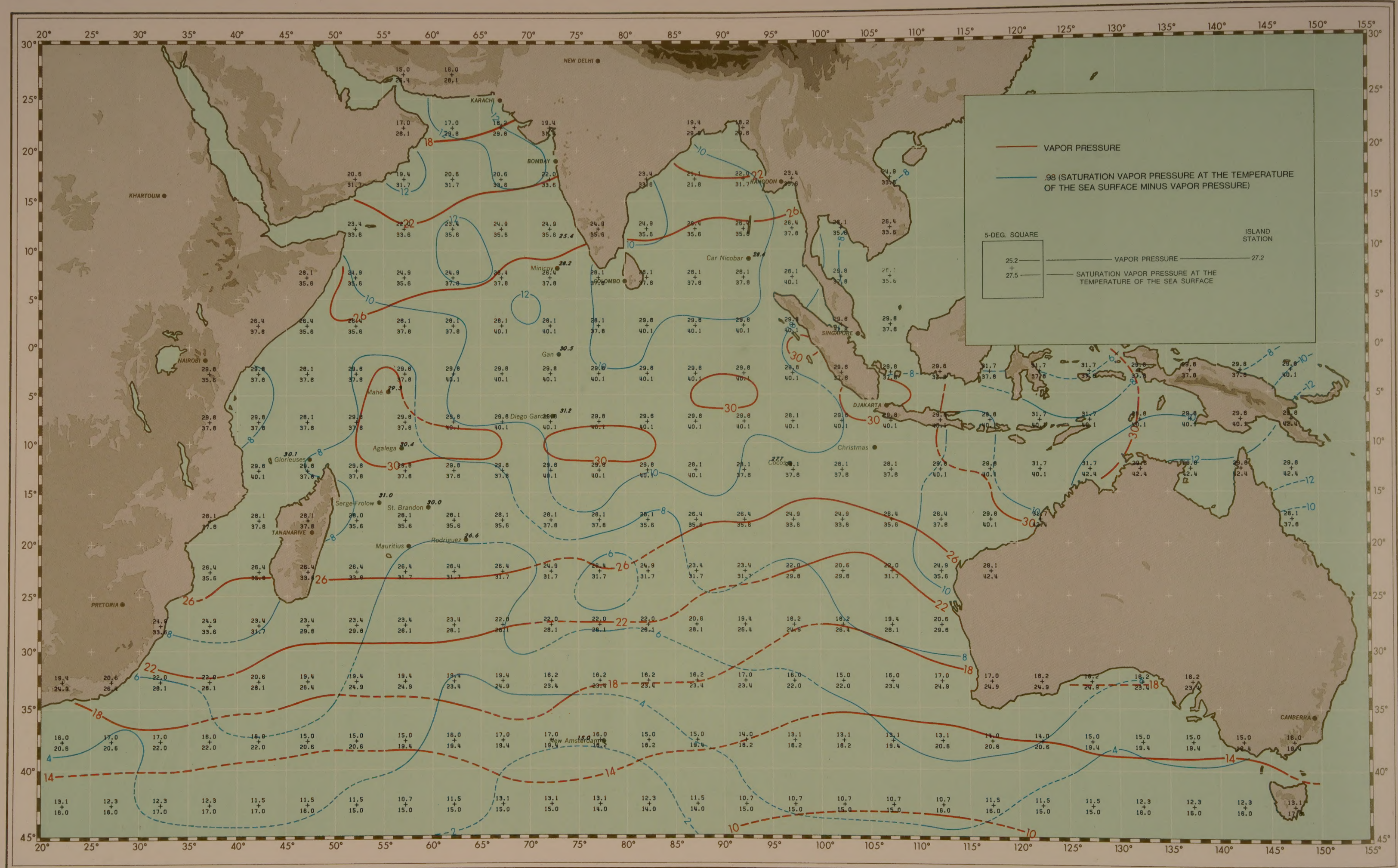


# VAPOR PRESSURE IN MILLIBARS December 1963 Chart 84



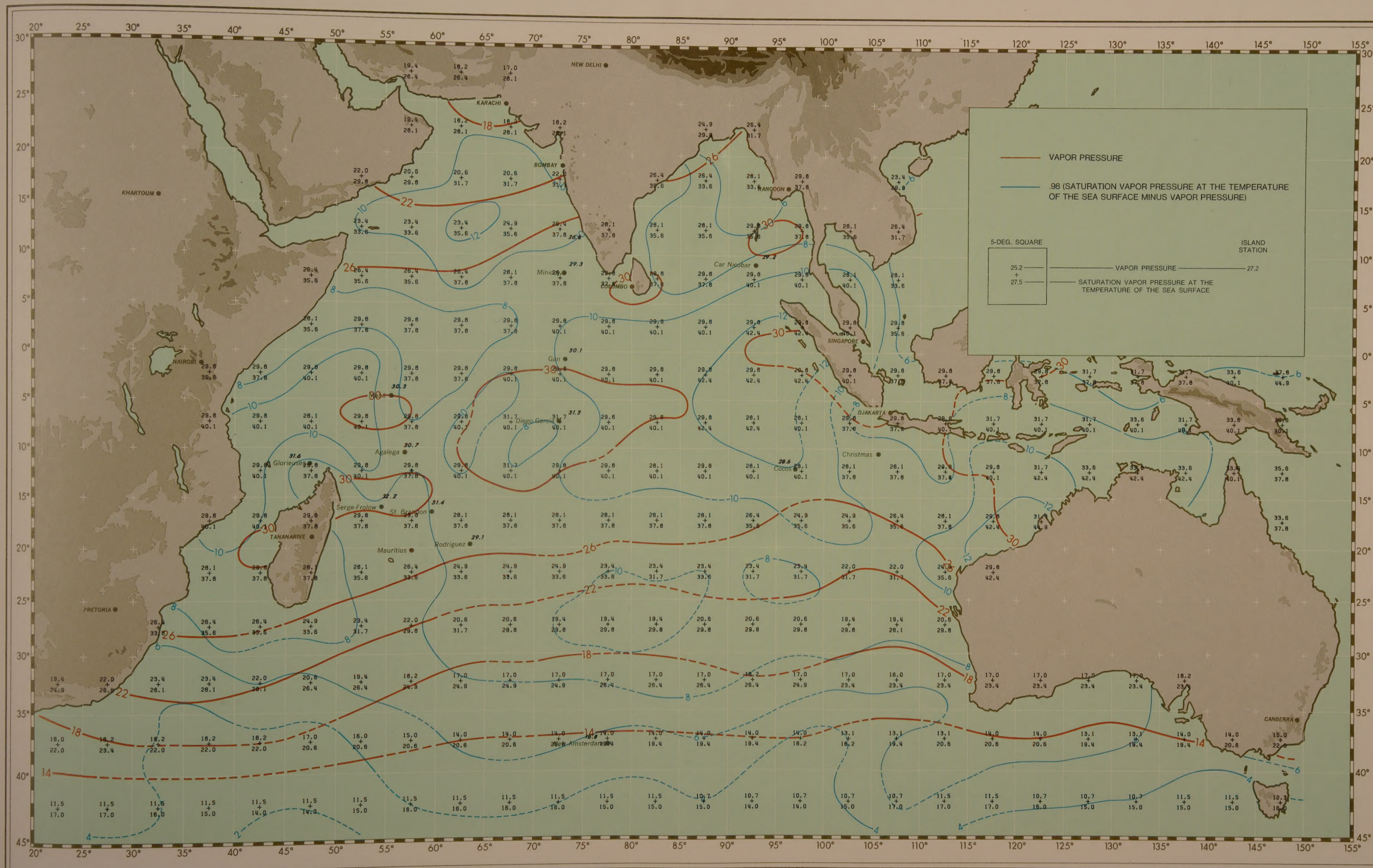


# VAPOR PRESSURE IN MILLIBARS January 1964 Chart 85



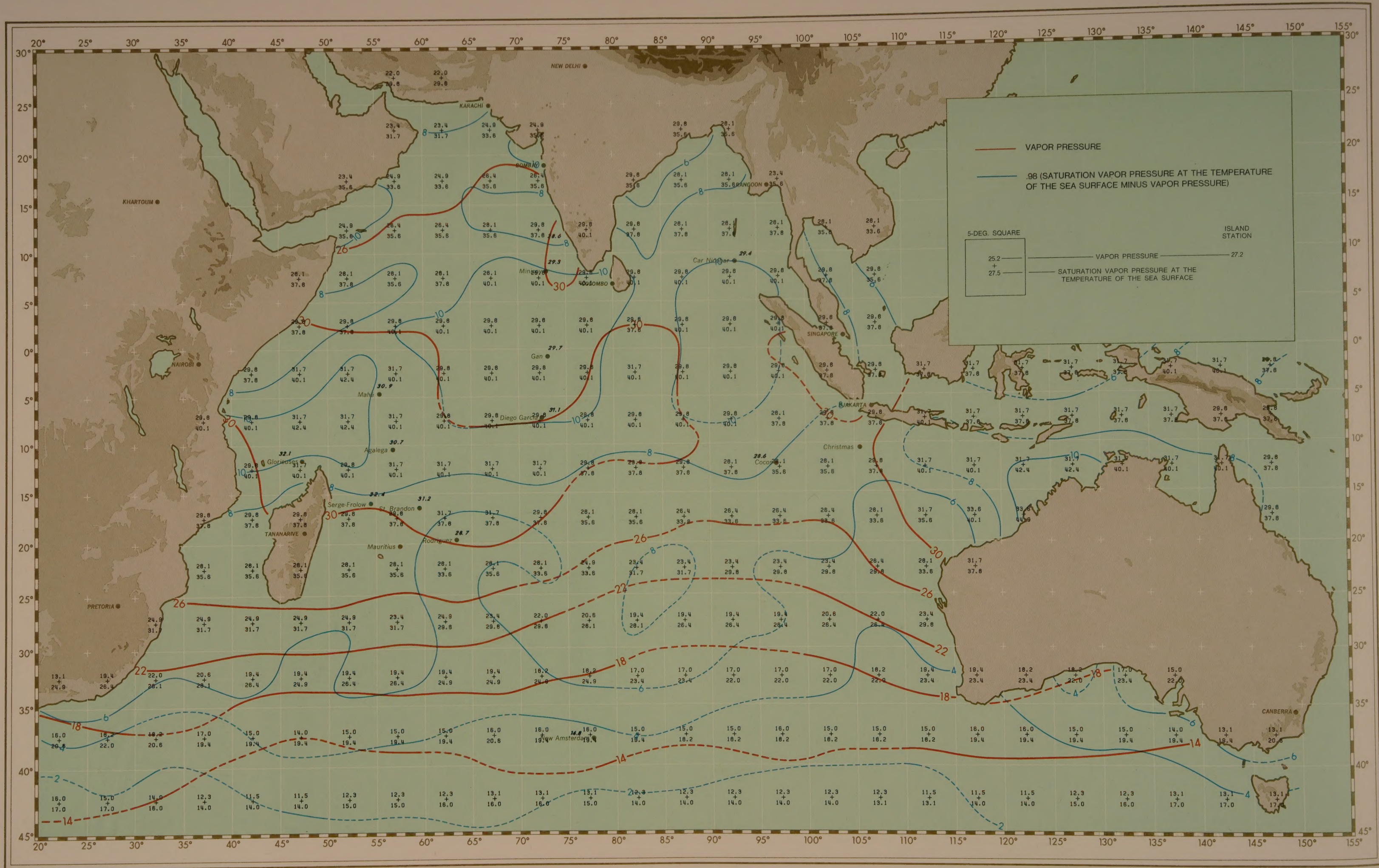


# VAPOR PRESSURE IN MILLIBARS February 1964 Chart 86



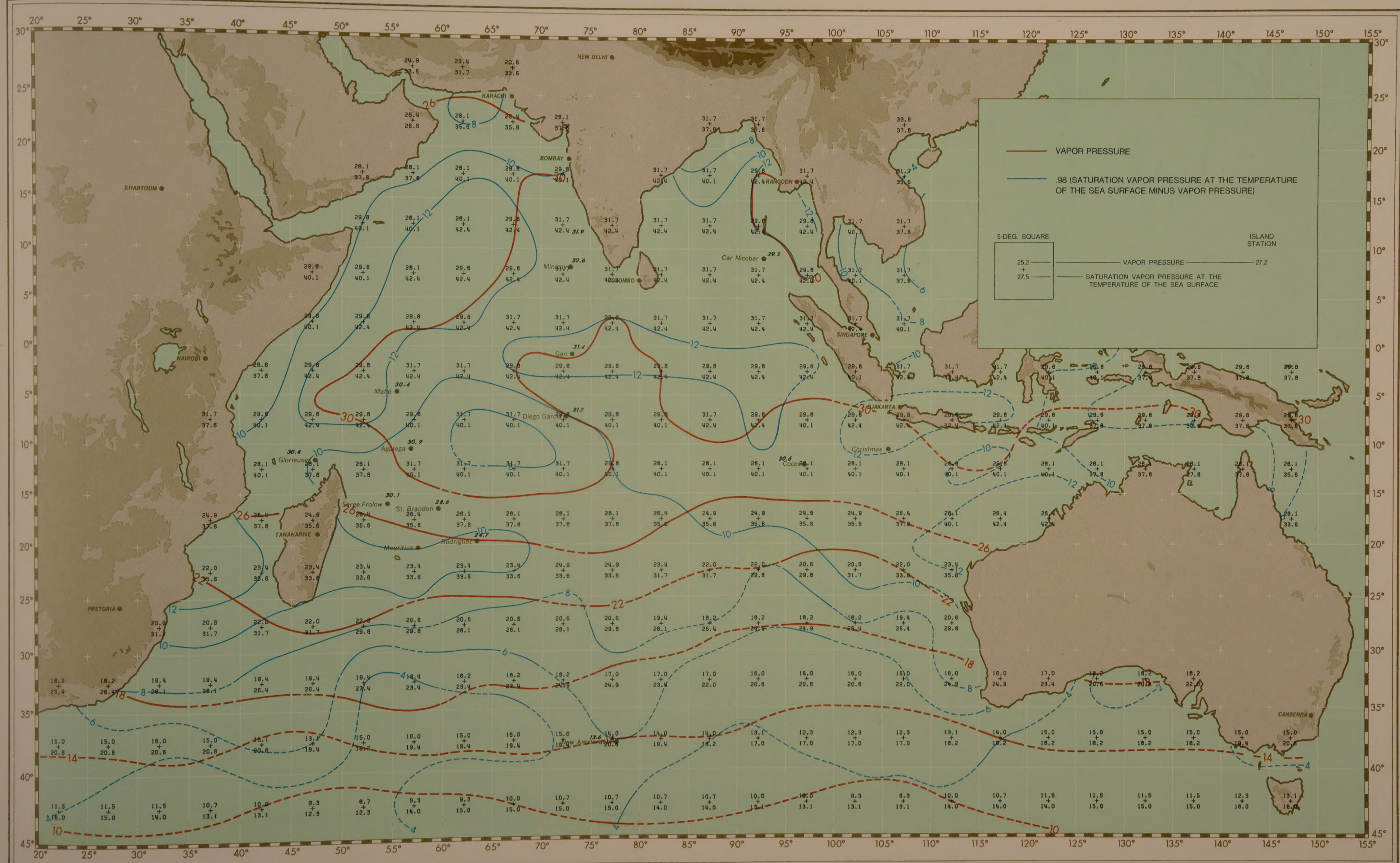


## VAPOR PRESSURE IN MILLIBARS March 1964 Chart 87



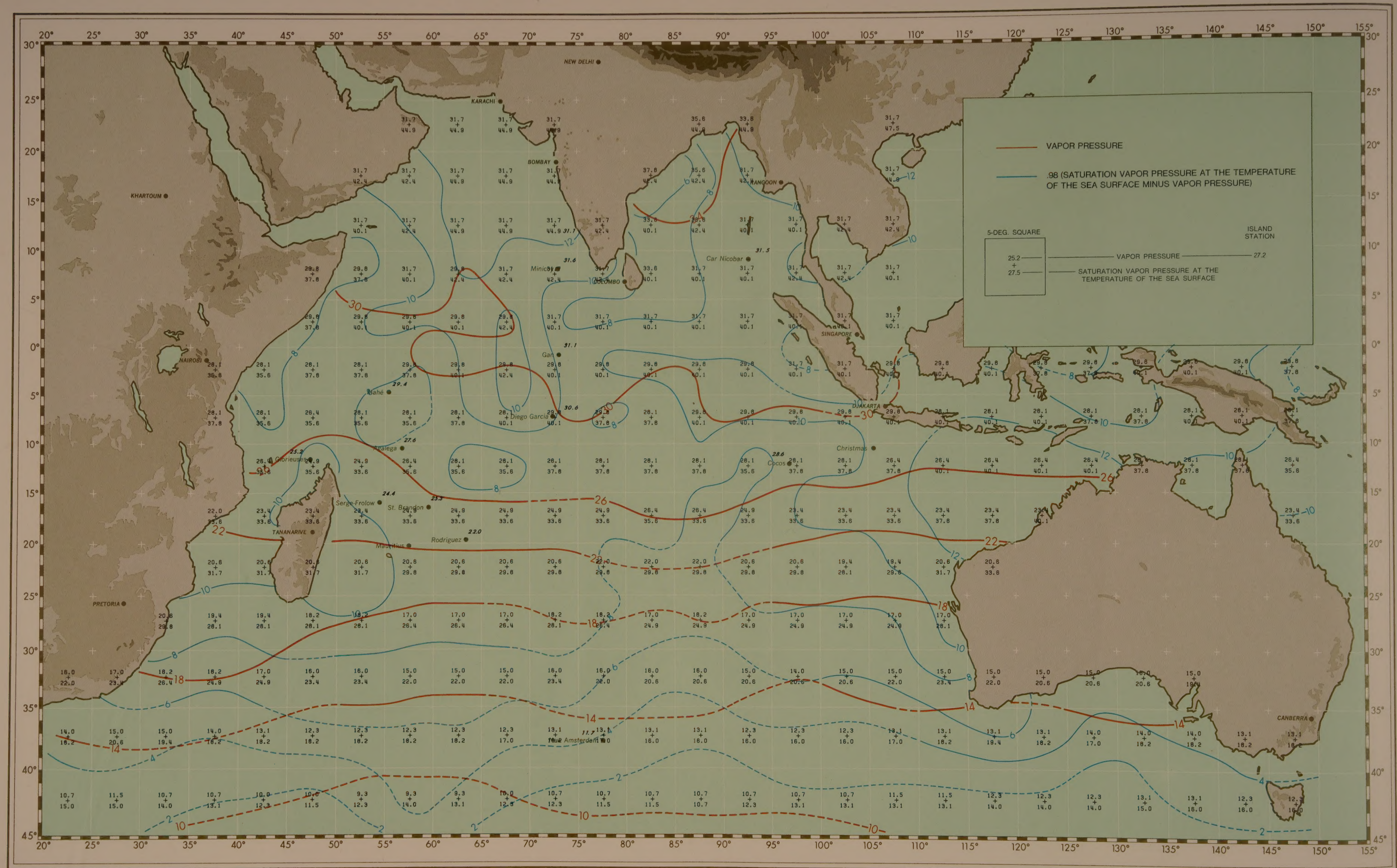


# VAPOR PRESSURE IN MILLIBARS April 1964 Chart 88



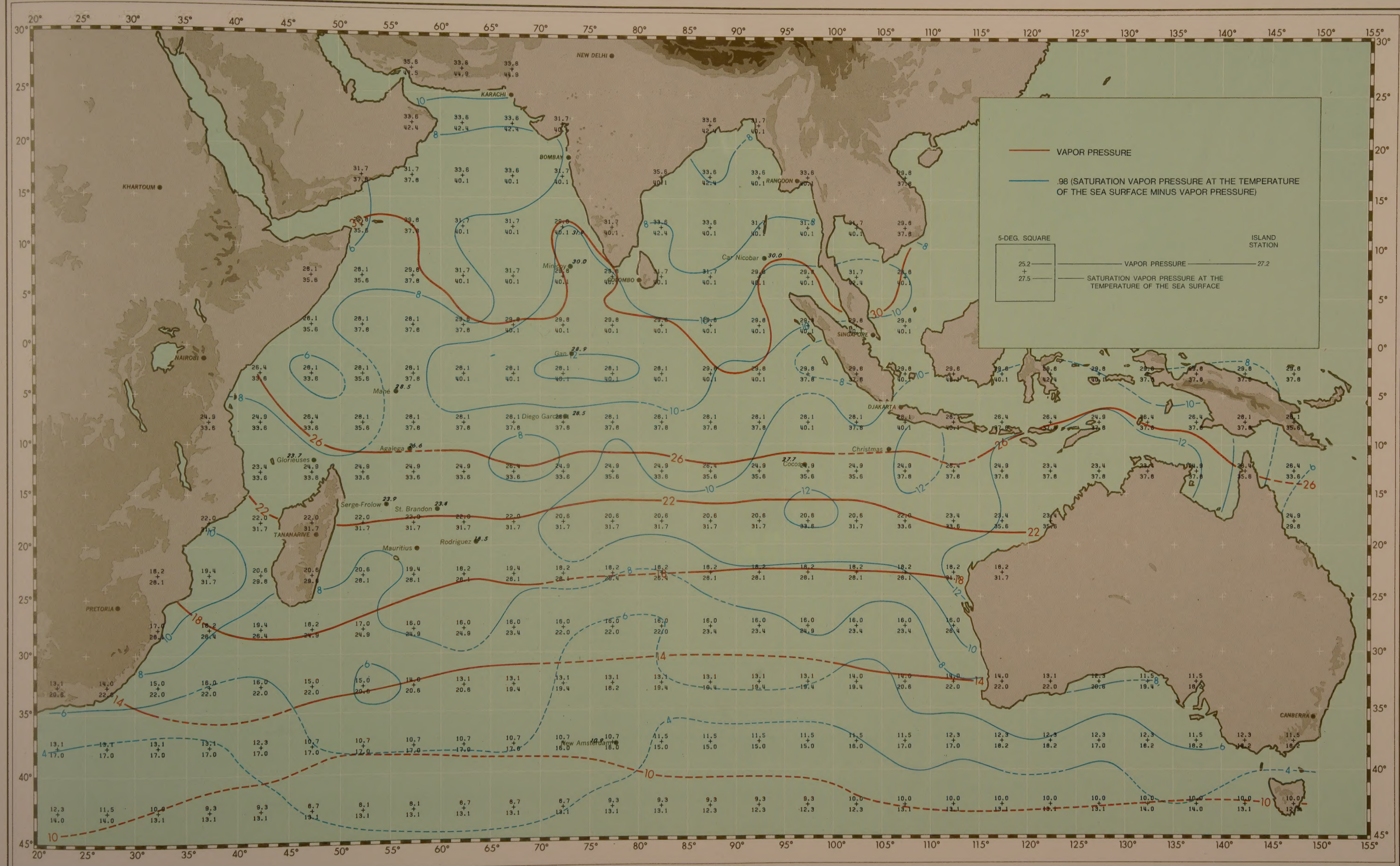


# VAPOR PRESSURE IN MILLIBARS May 1964 Chart 89



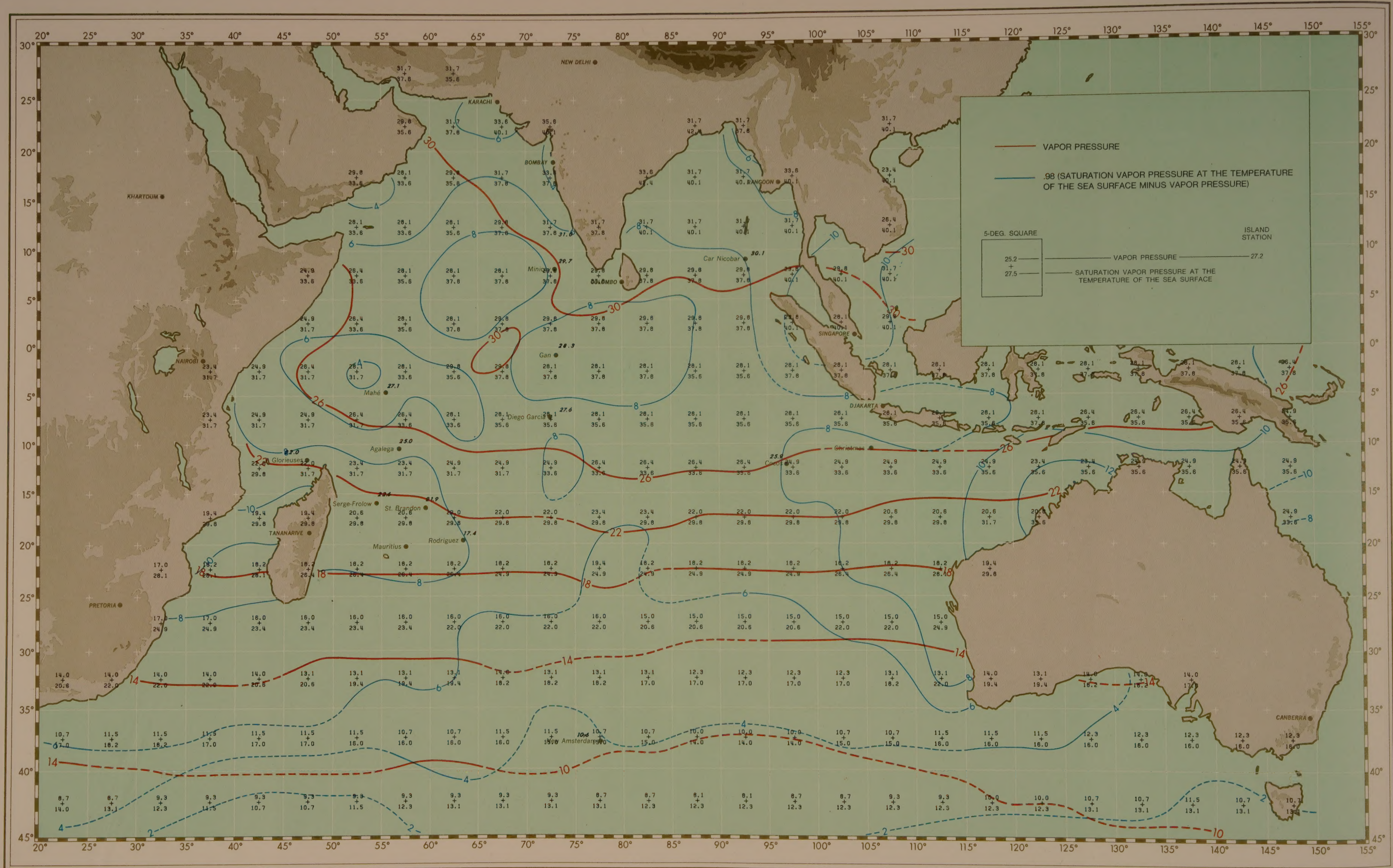


# VAPOR PRESSURE IN MILLIBARS June 1964 Chart 90



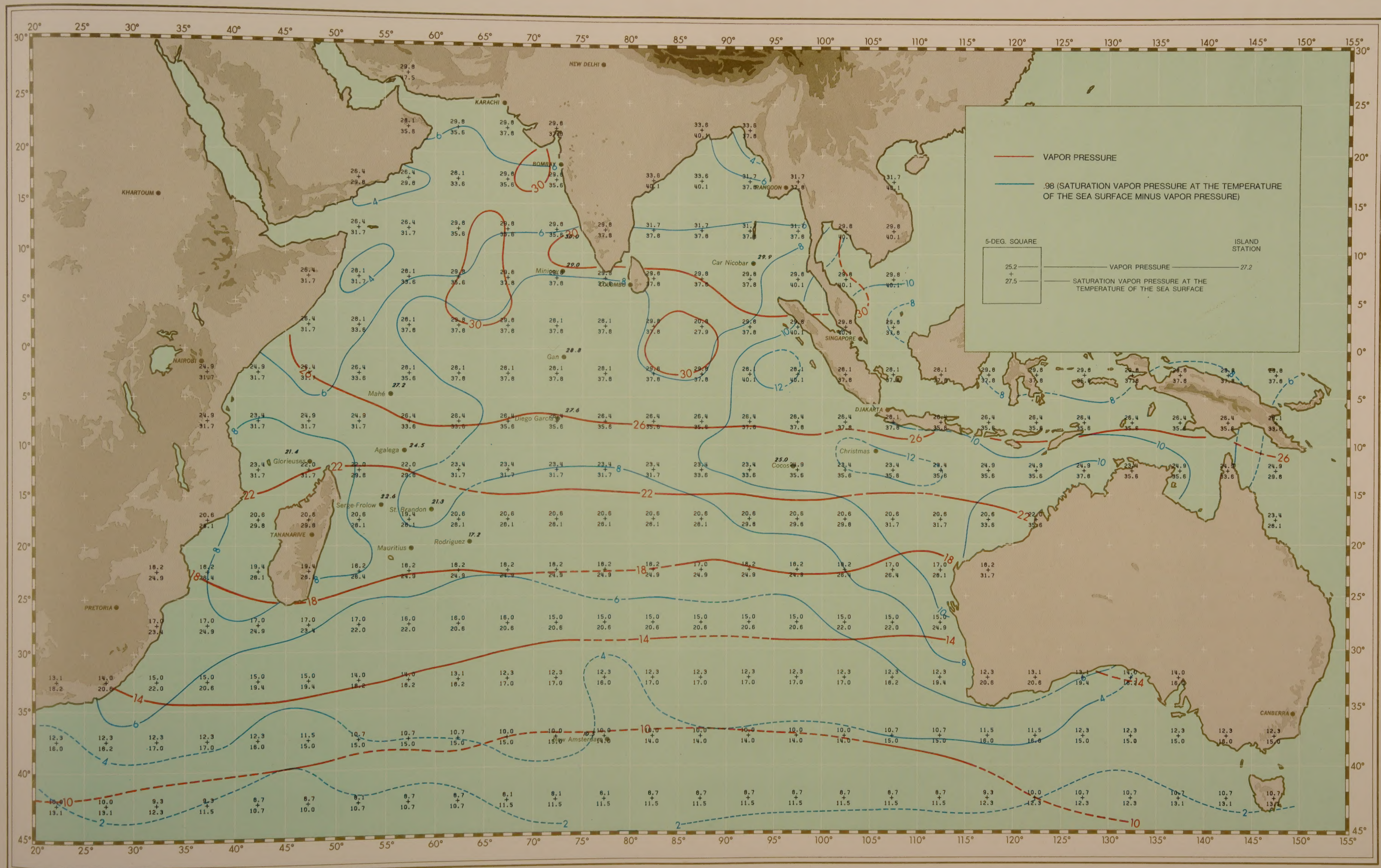


# VAPOR PRESSURE IN MILLIBARS July 1964 Chart 91





### Chart 92

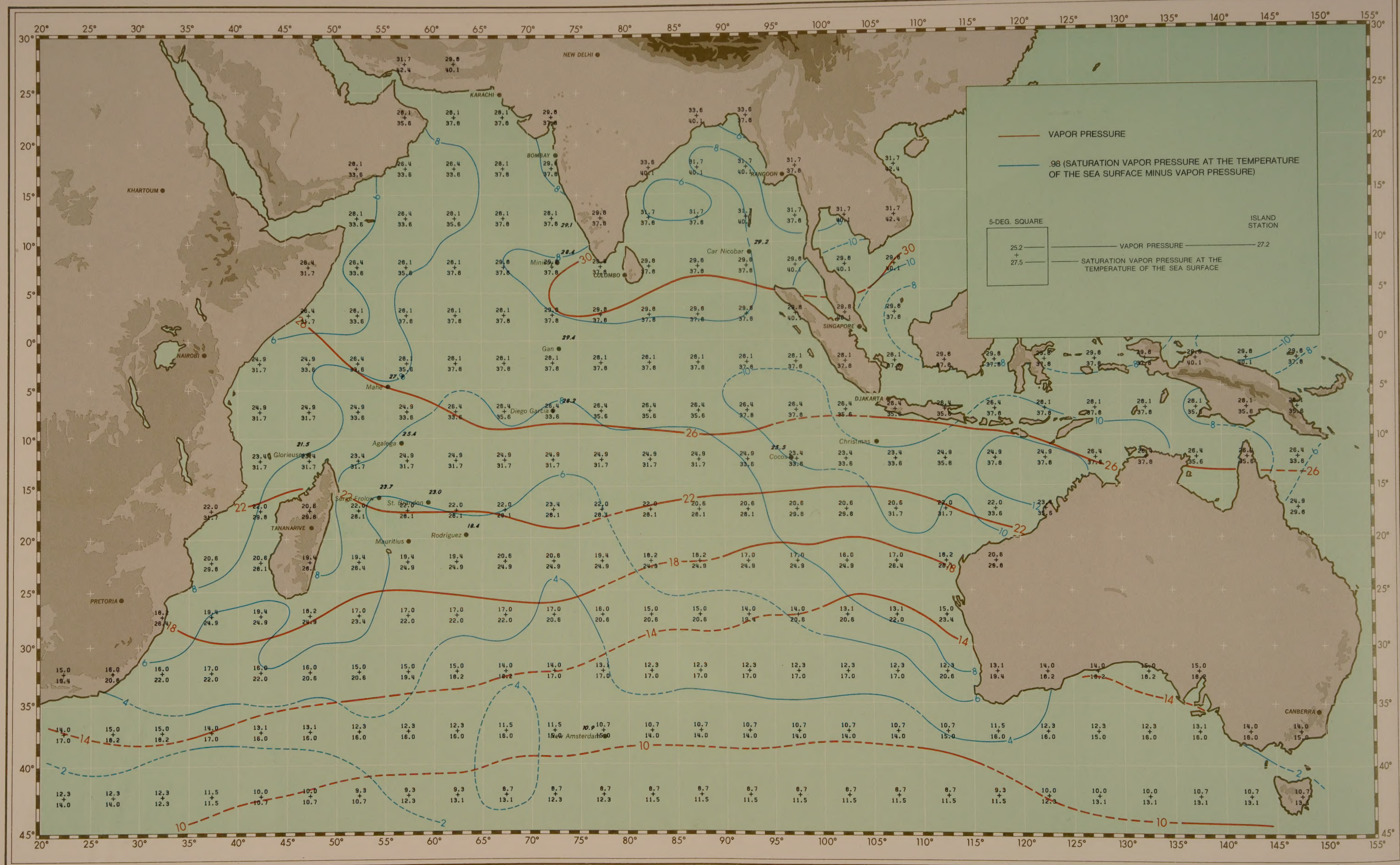




## VAPOR PRESSURE IN MILLIBARS

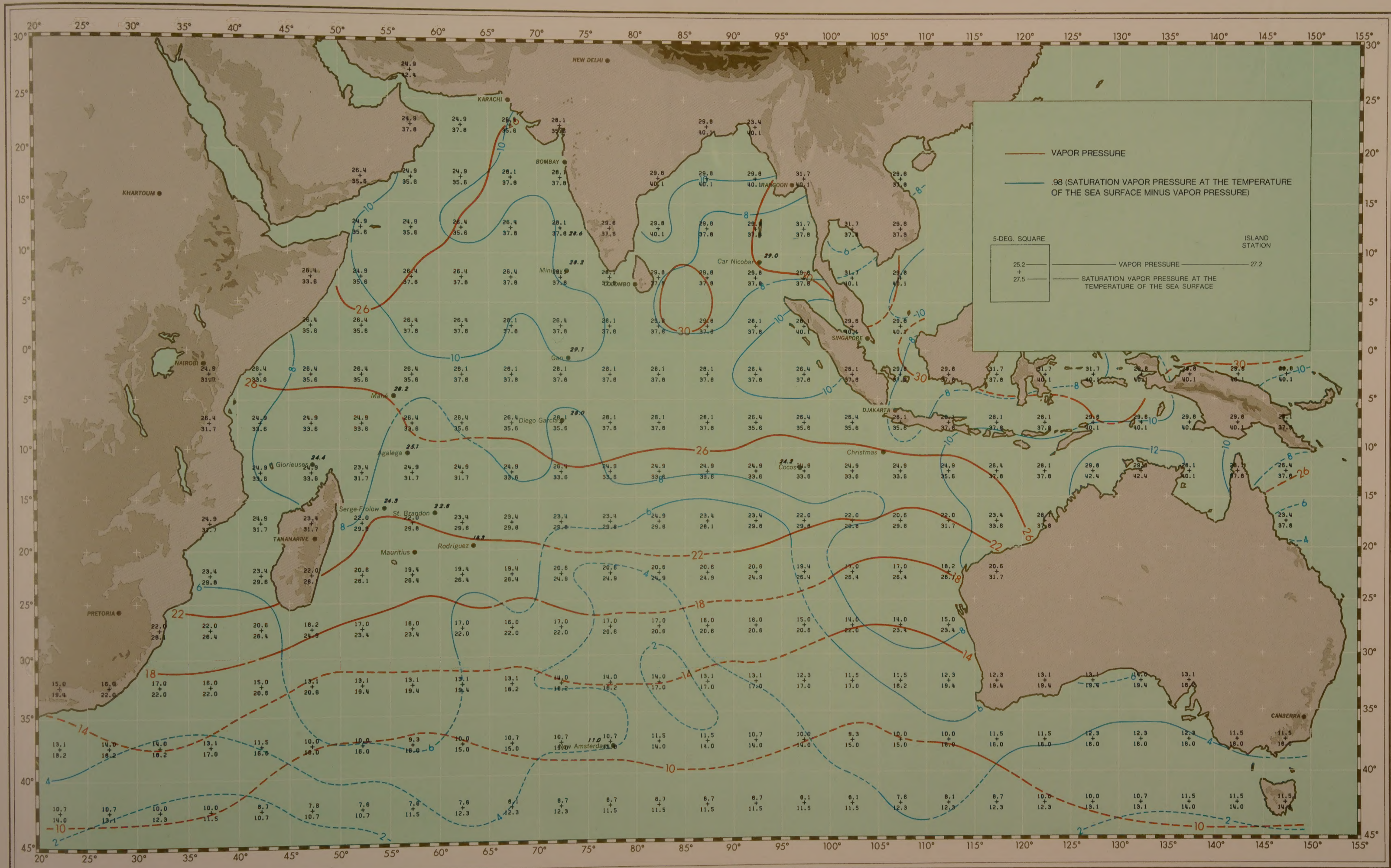
## September 1964

### Chart 93



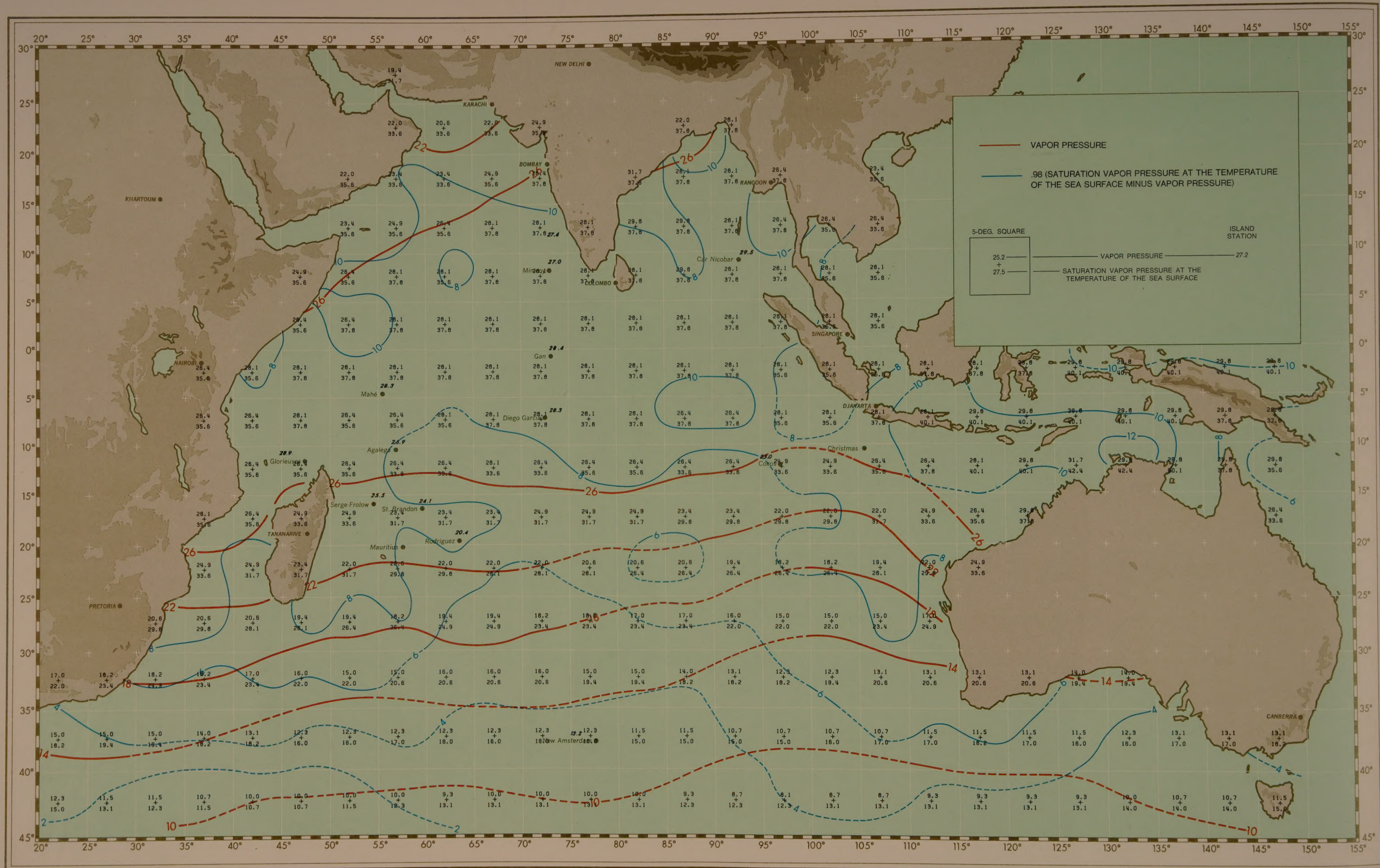


### Chart 94



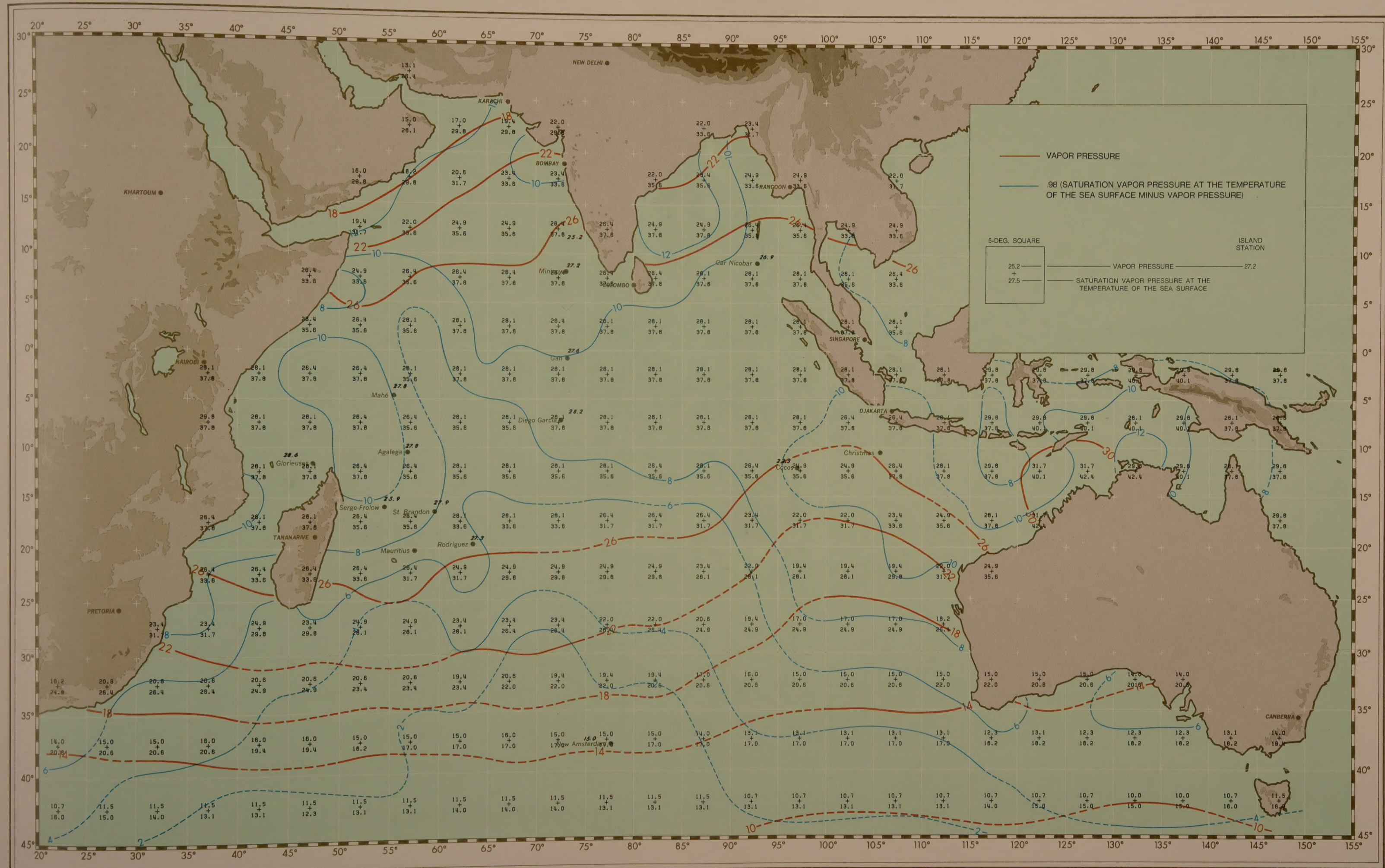


# VAPOR PRESSURE IN MILLIBARS November 1964 Chart 95





# VAPOR PRESSURE IN MILLIBARS December 1964 Chart 96





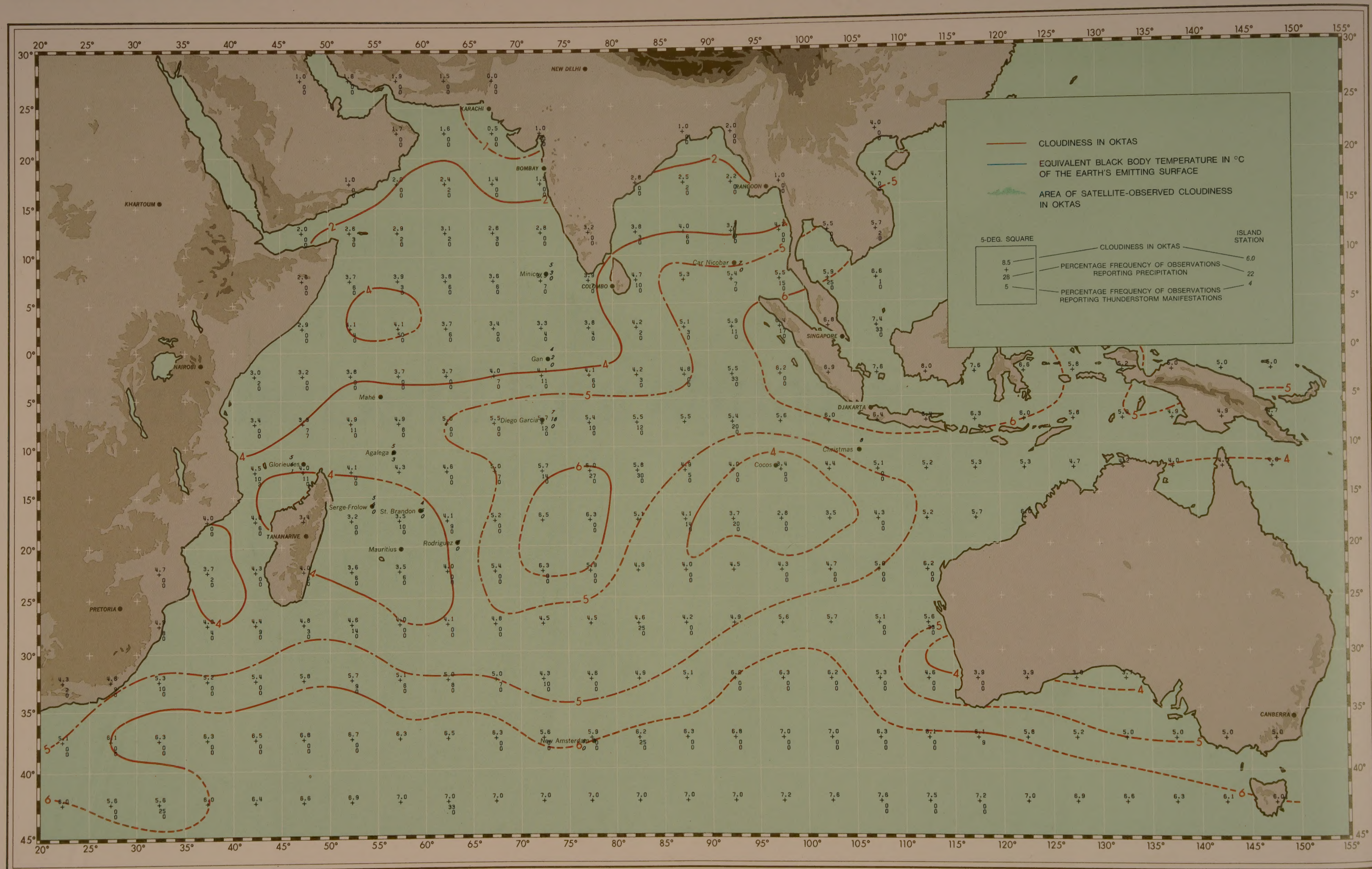




# Clouds and Precipitation

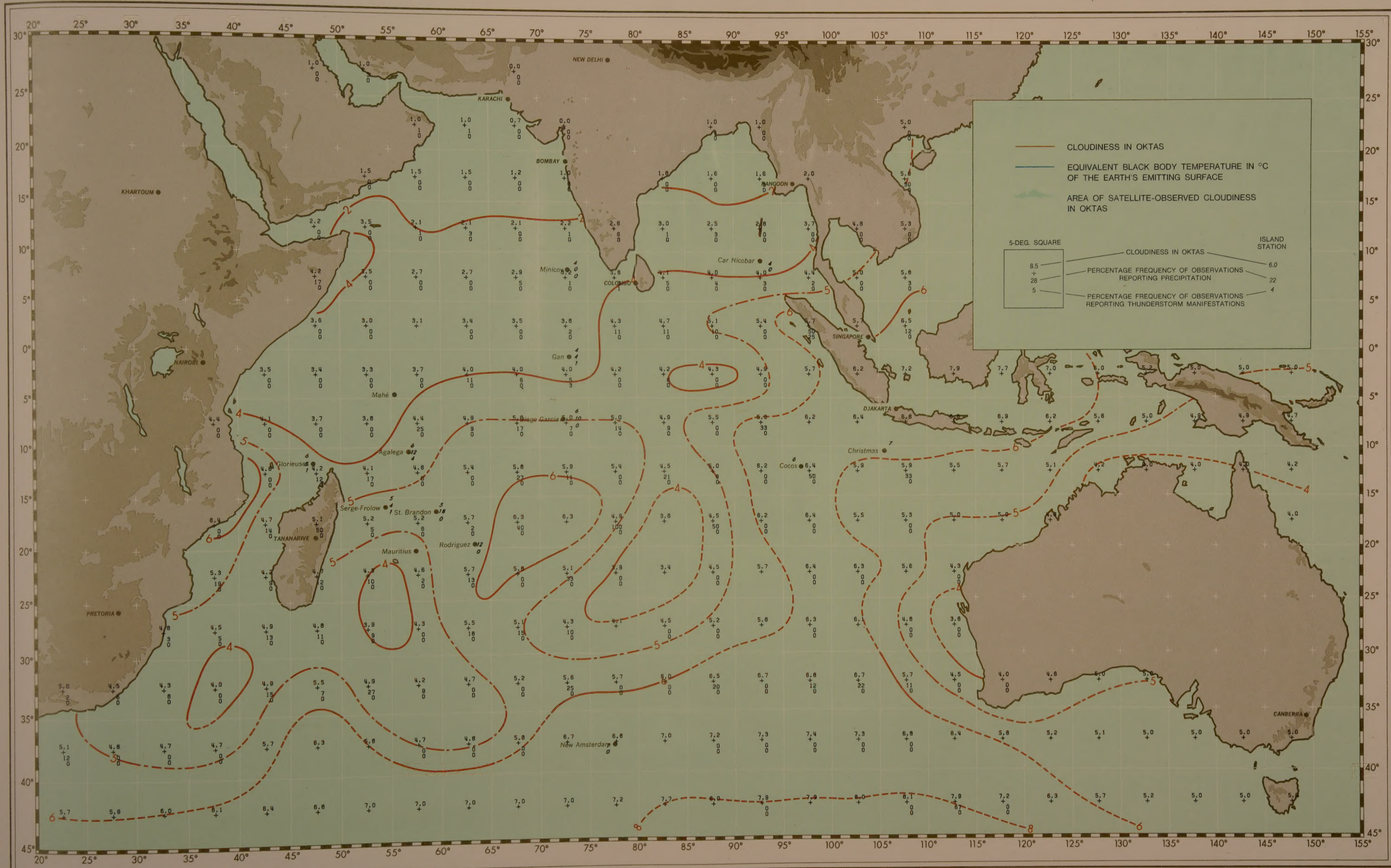


# CLOUDS AND PRECIPITATION January 1963 Chart 97



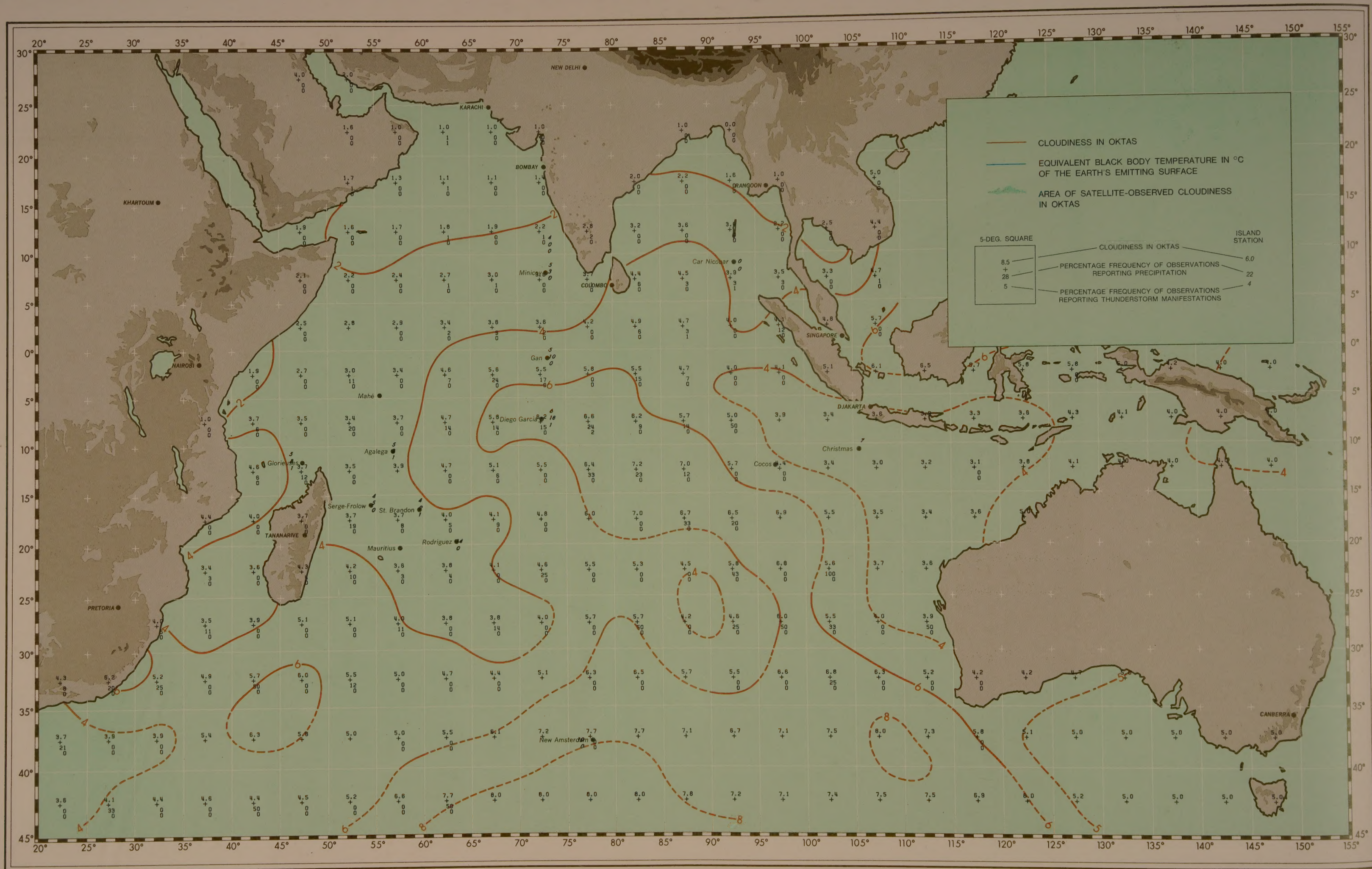


# CLOUDS AND PRECIPITATION February 1963 Chart 98



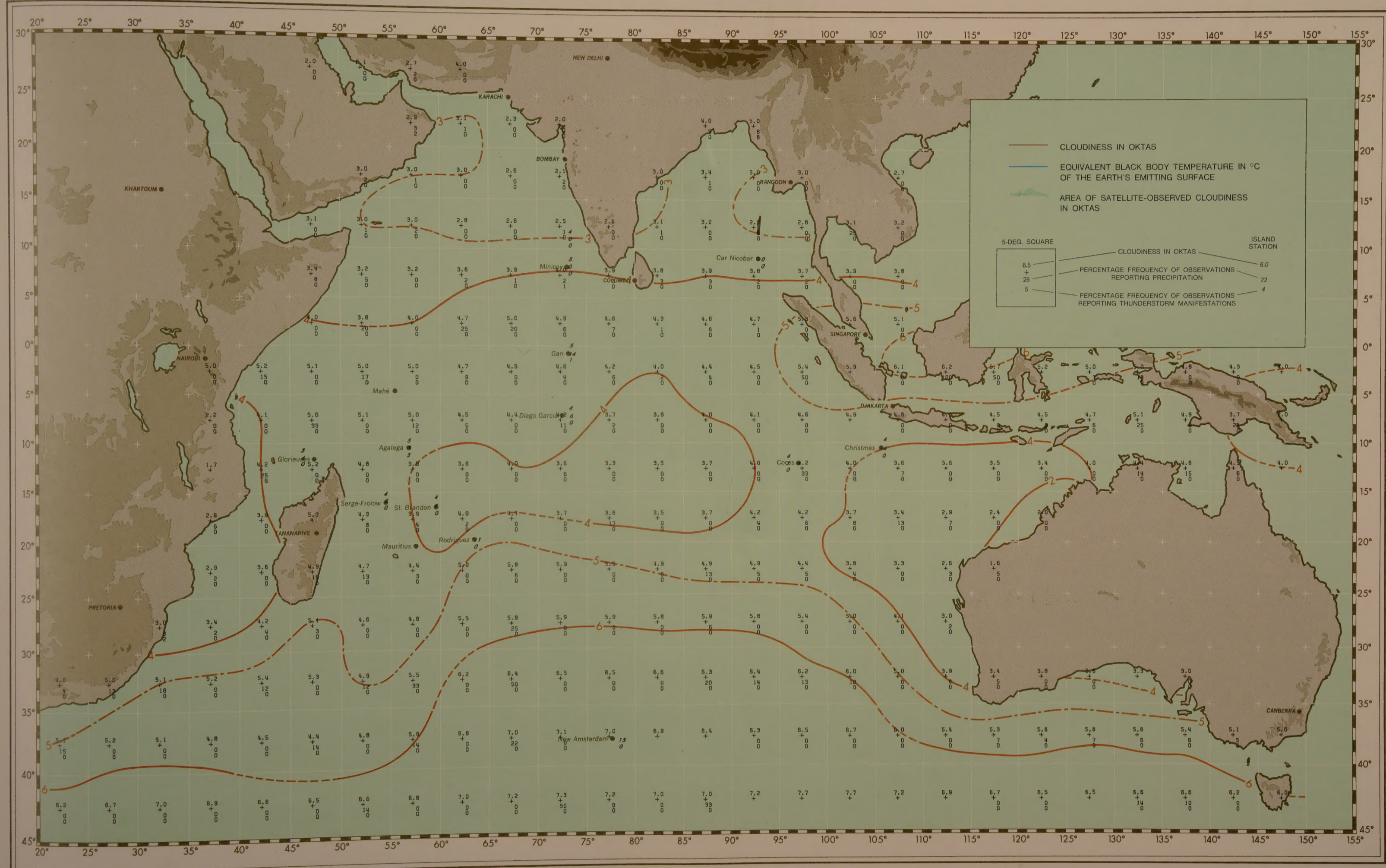


# CLOUDS AND PRECIPITATION March 1963 Chart 99



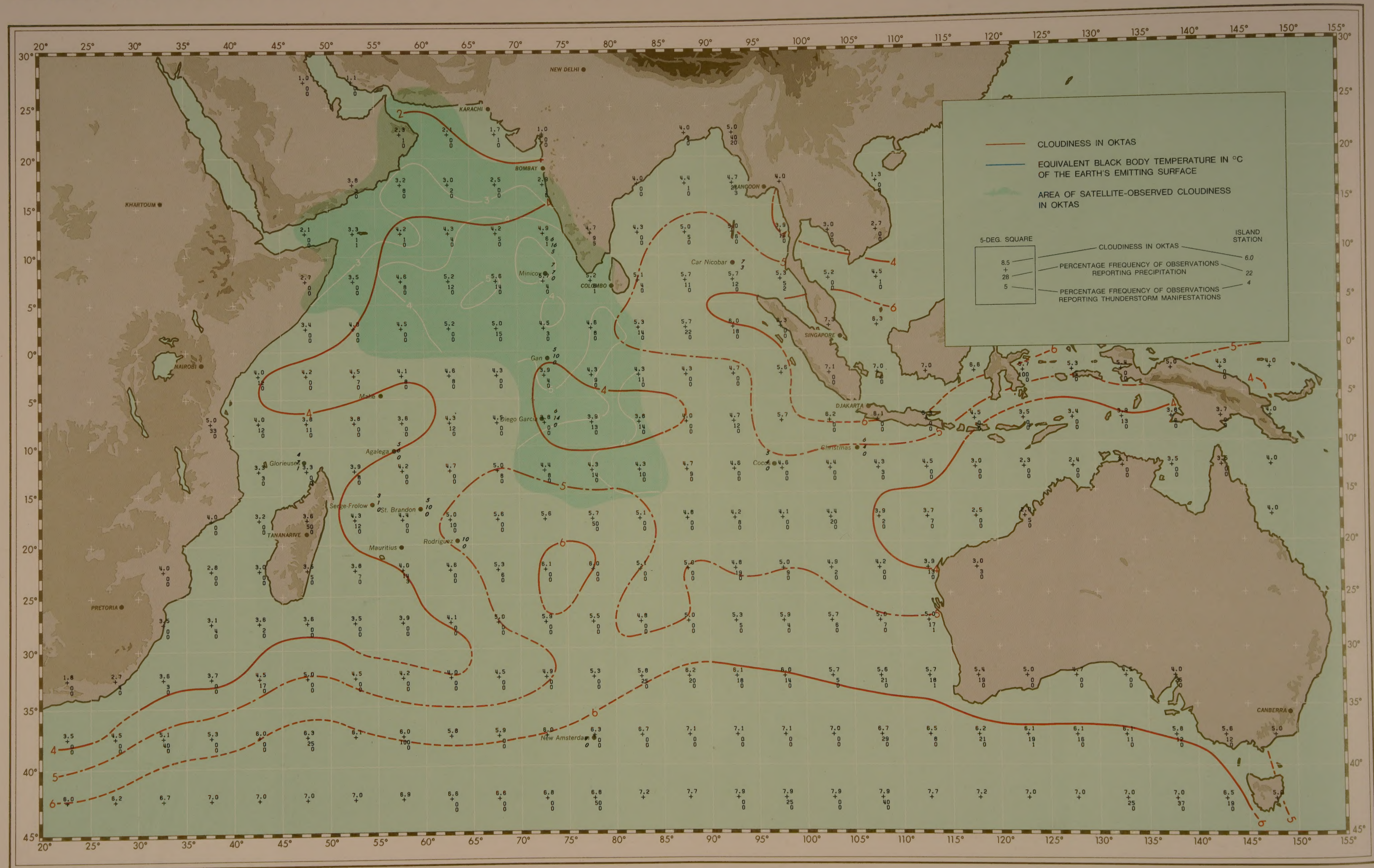


# CLOUDS AND PRECIPITATION April 1963 Chart 100



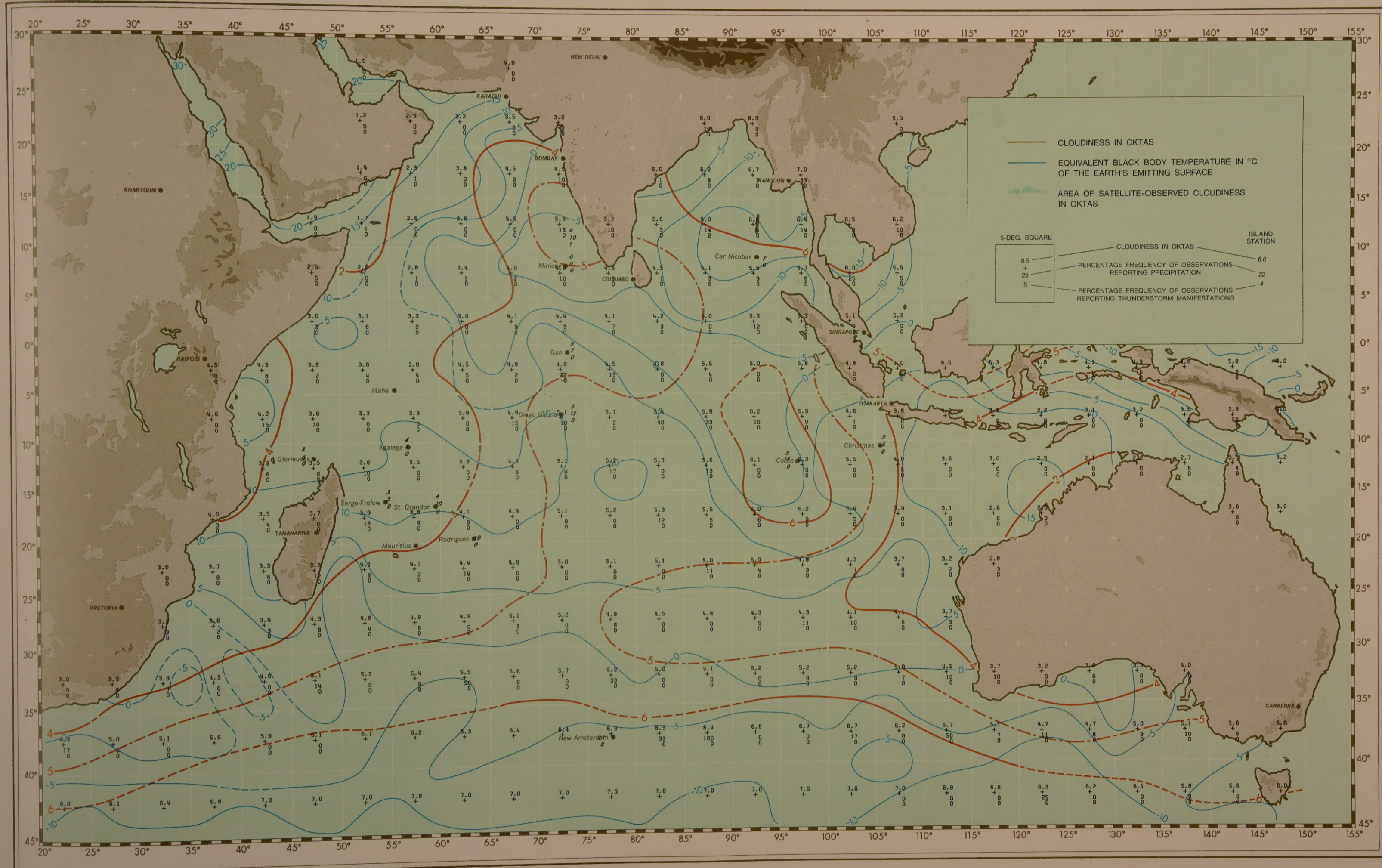


# CLOUDS AND PRECIPITATION May 1963 Chart 101



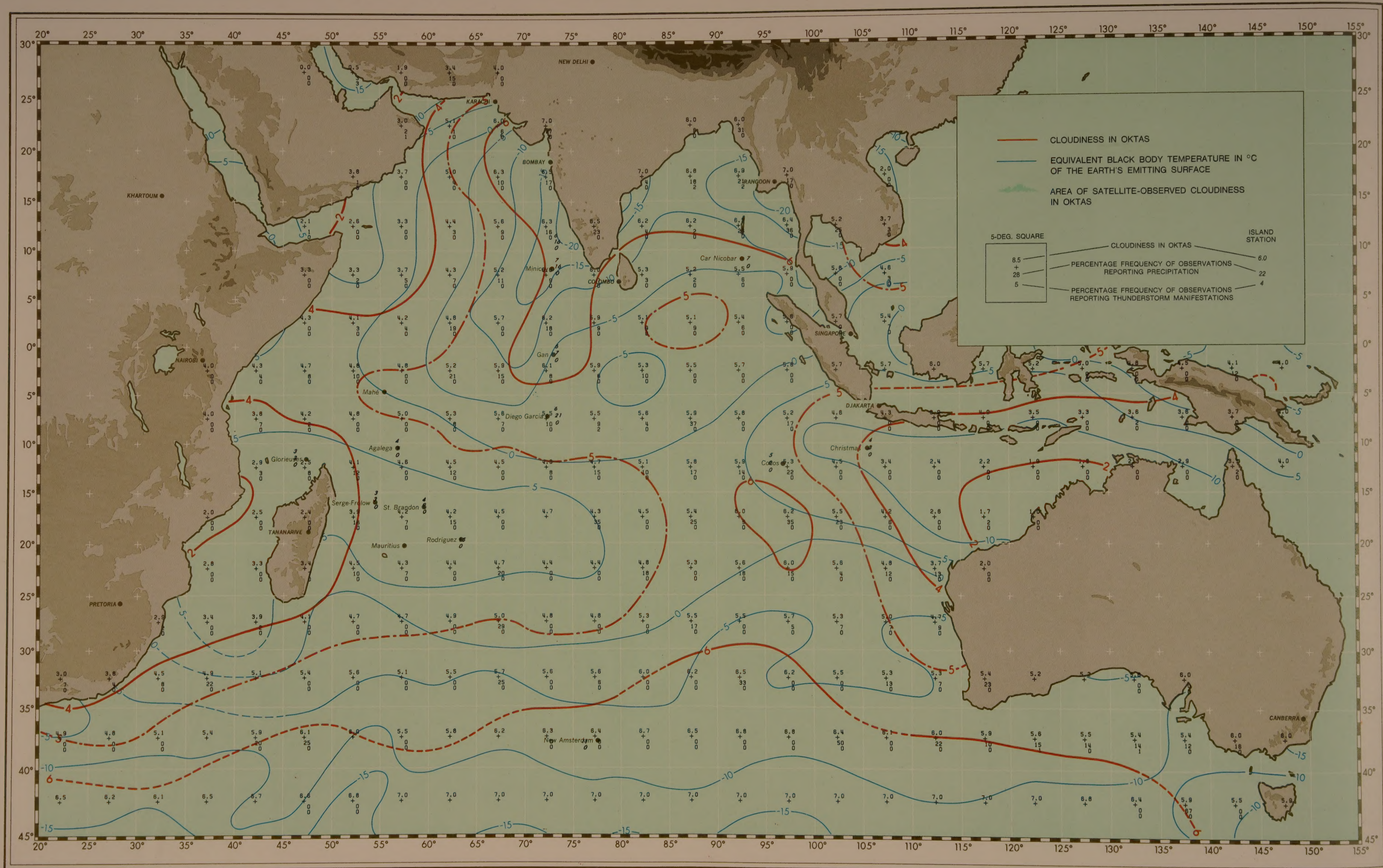


# CLOUDS AND PRECIPITATION June 1963 Chart 102



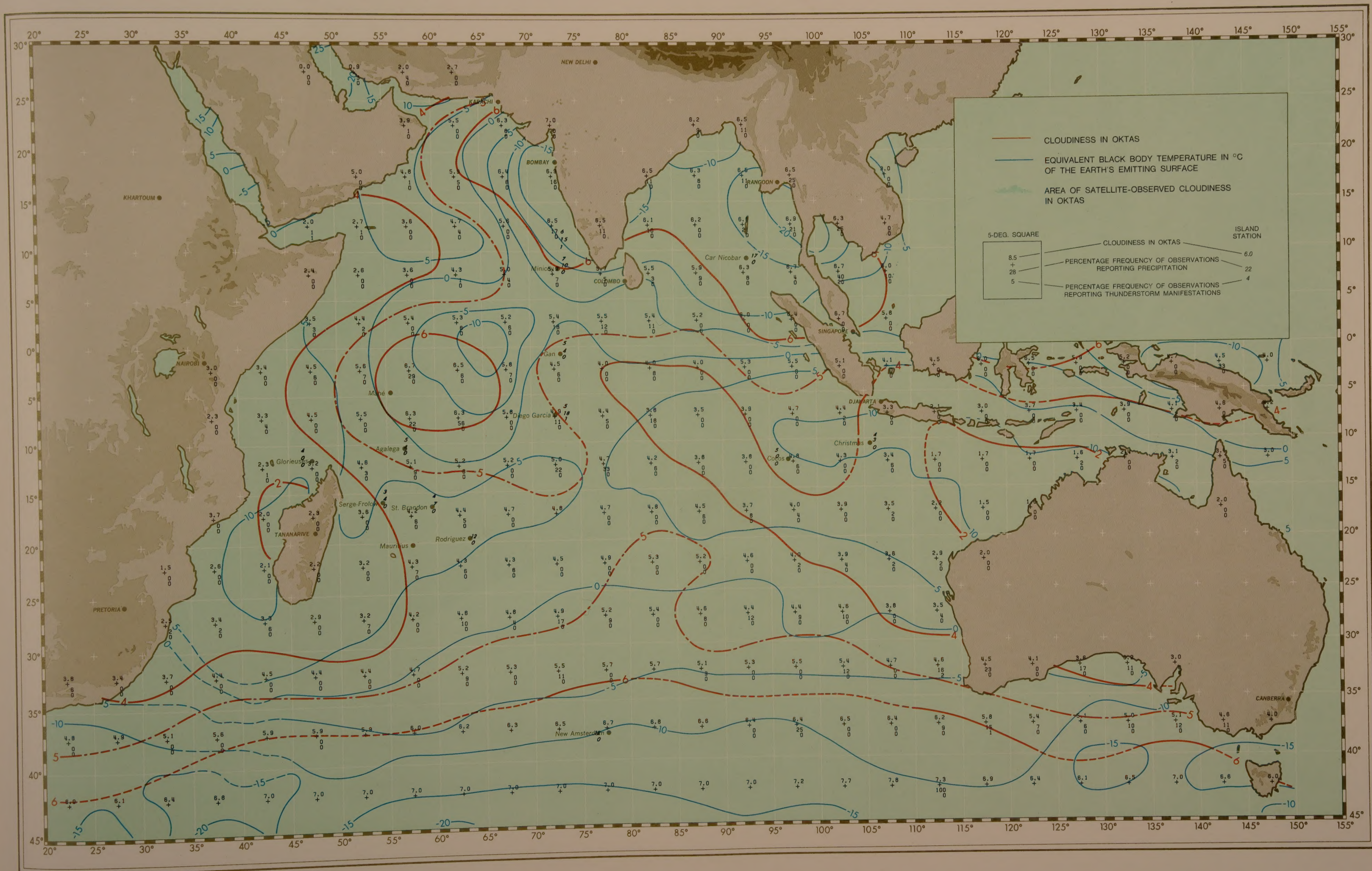


# CLOUDS AND PRECIPITATION July 1963 Chart 103



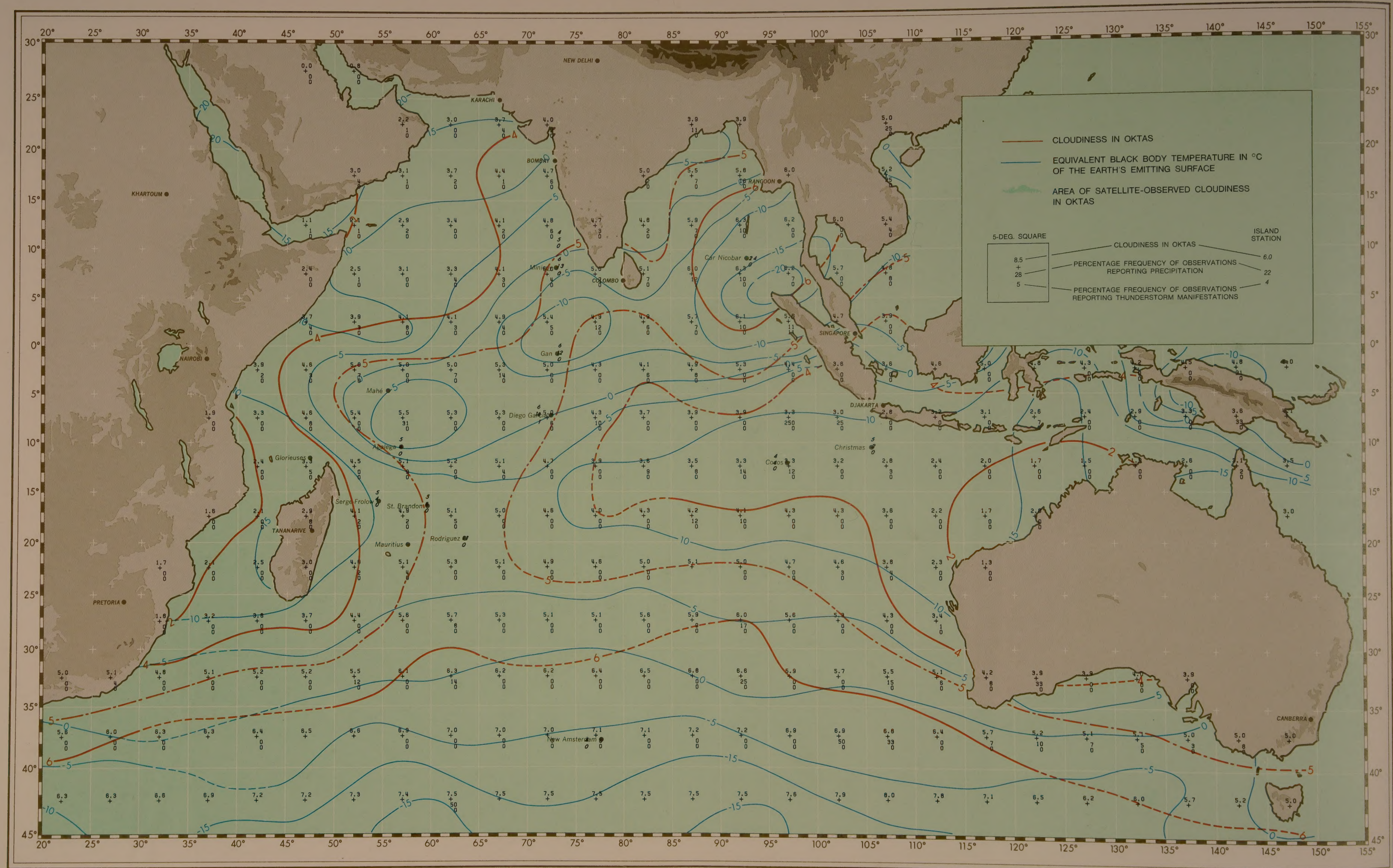


# CLOUDS AND PRECIPITATION August 1963 Chart 104



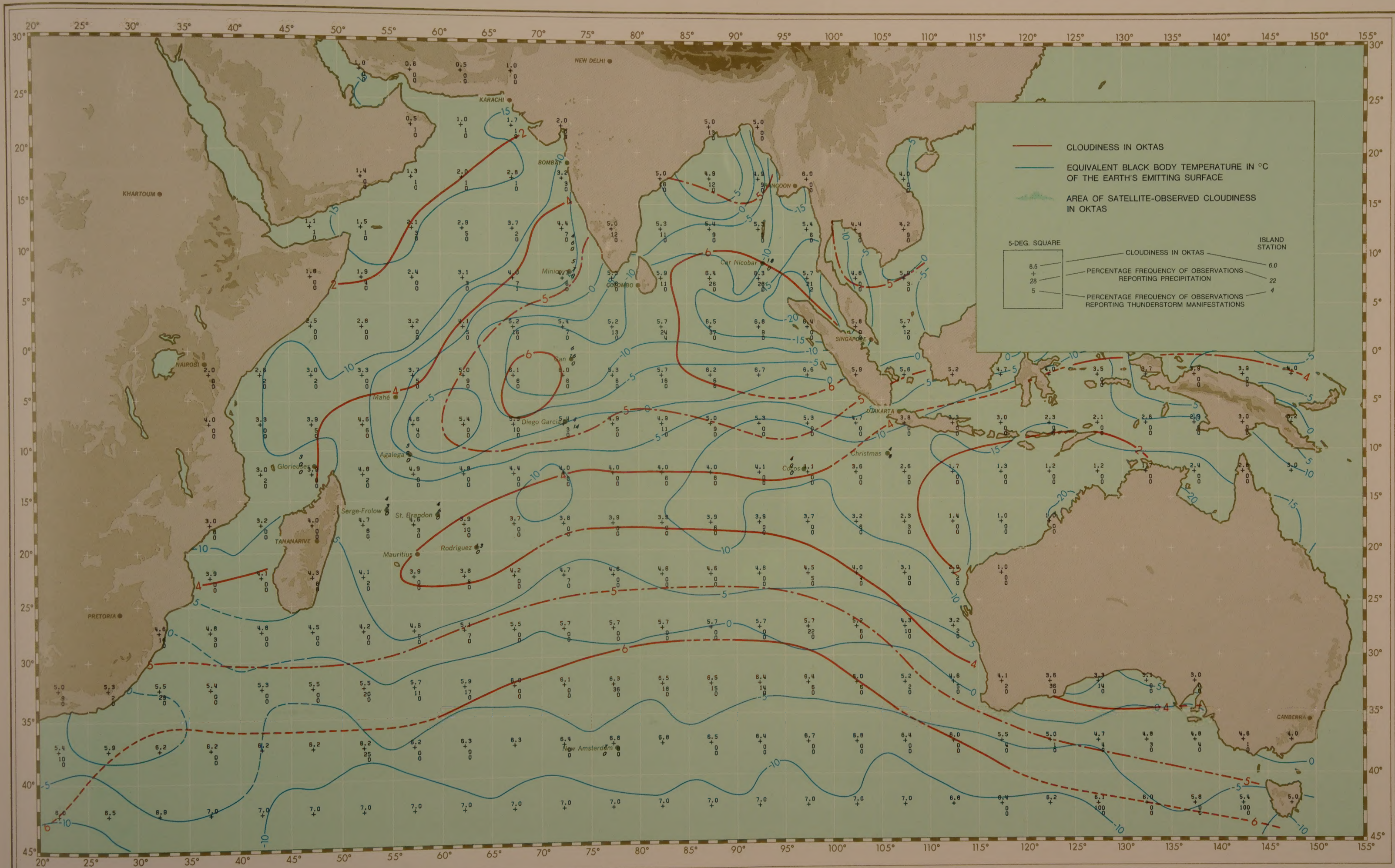


# CLOUDS AND PRECIPITATION September 1963 Chart 105



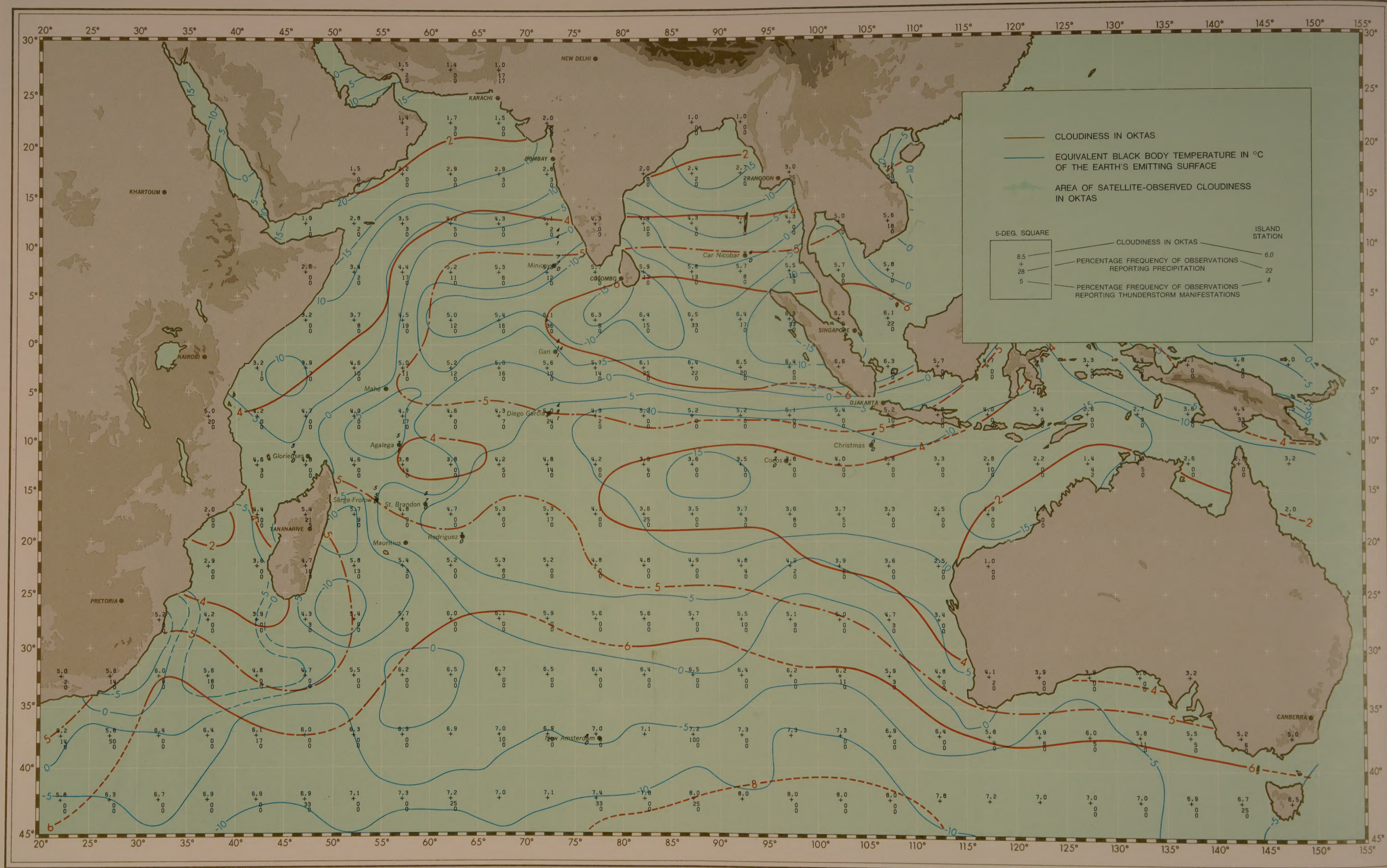


# CLOUDS AND PRECIPITATION    October 1963    Chart 106



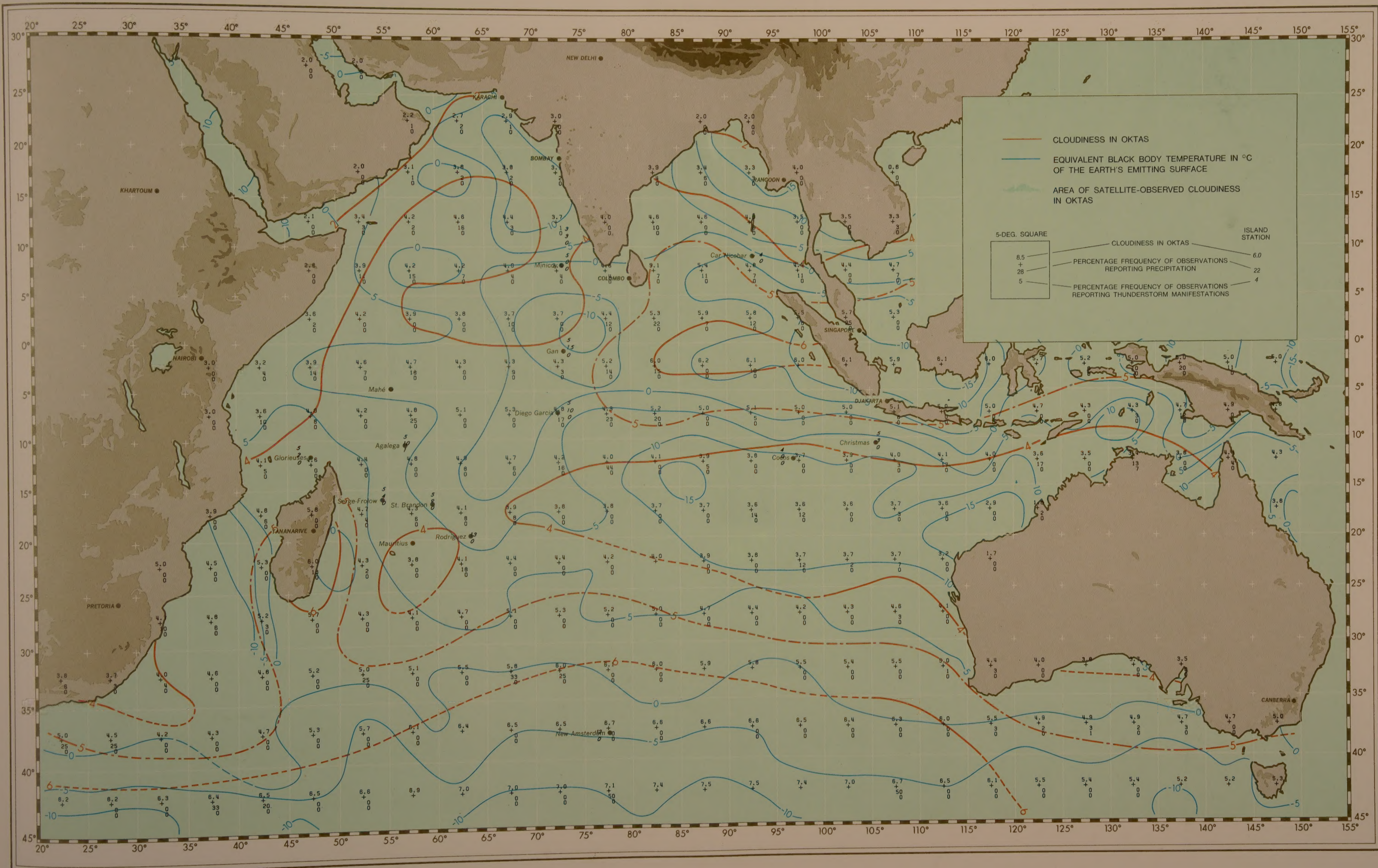


# CLOUDS AND PRECIPITATION November 1963 Chart 107



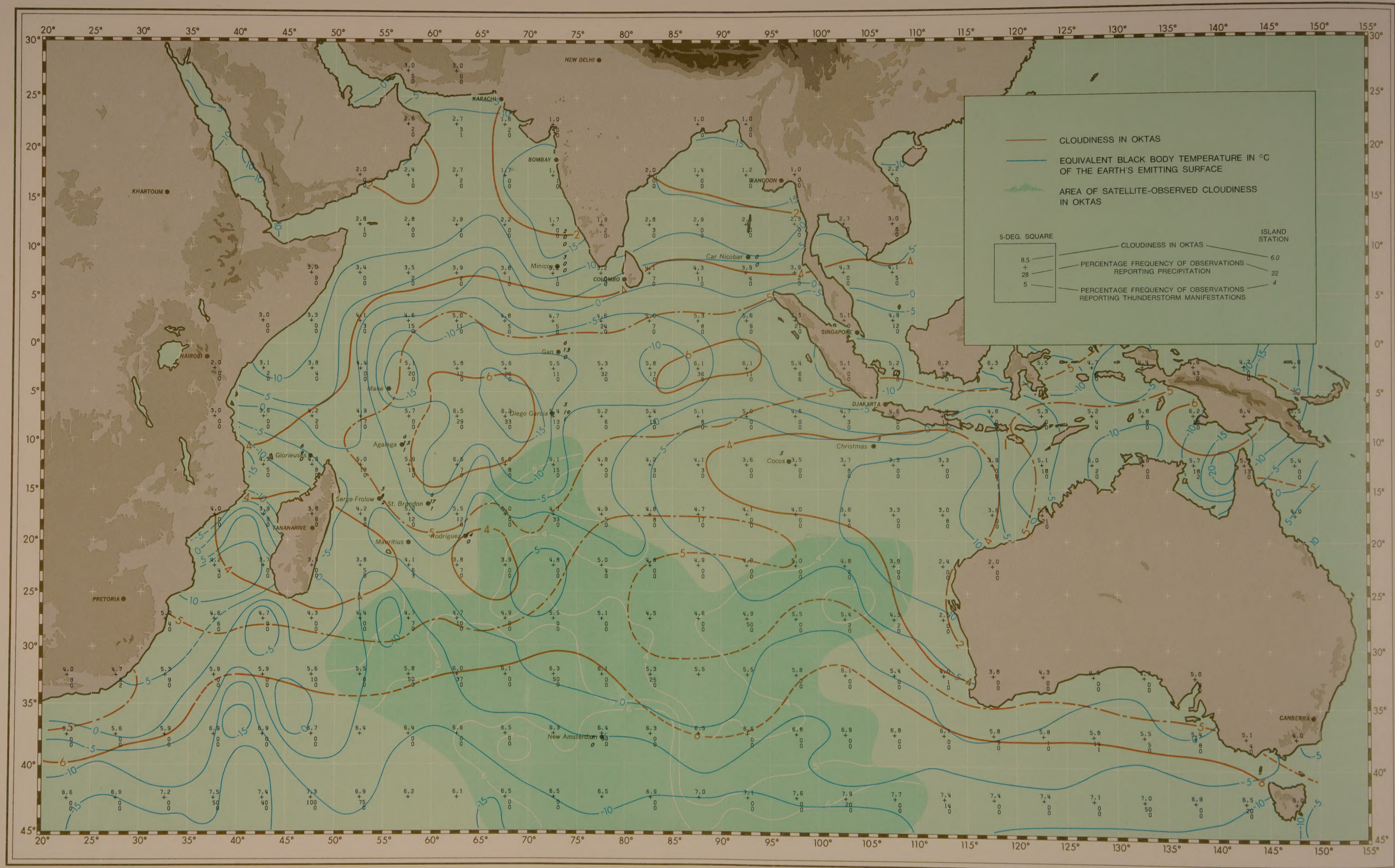


# CLOUDS AND PRECIPITATION December 1963 Chart 108



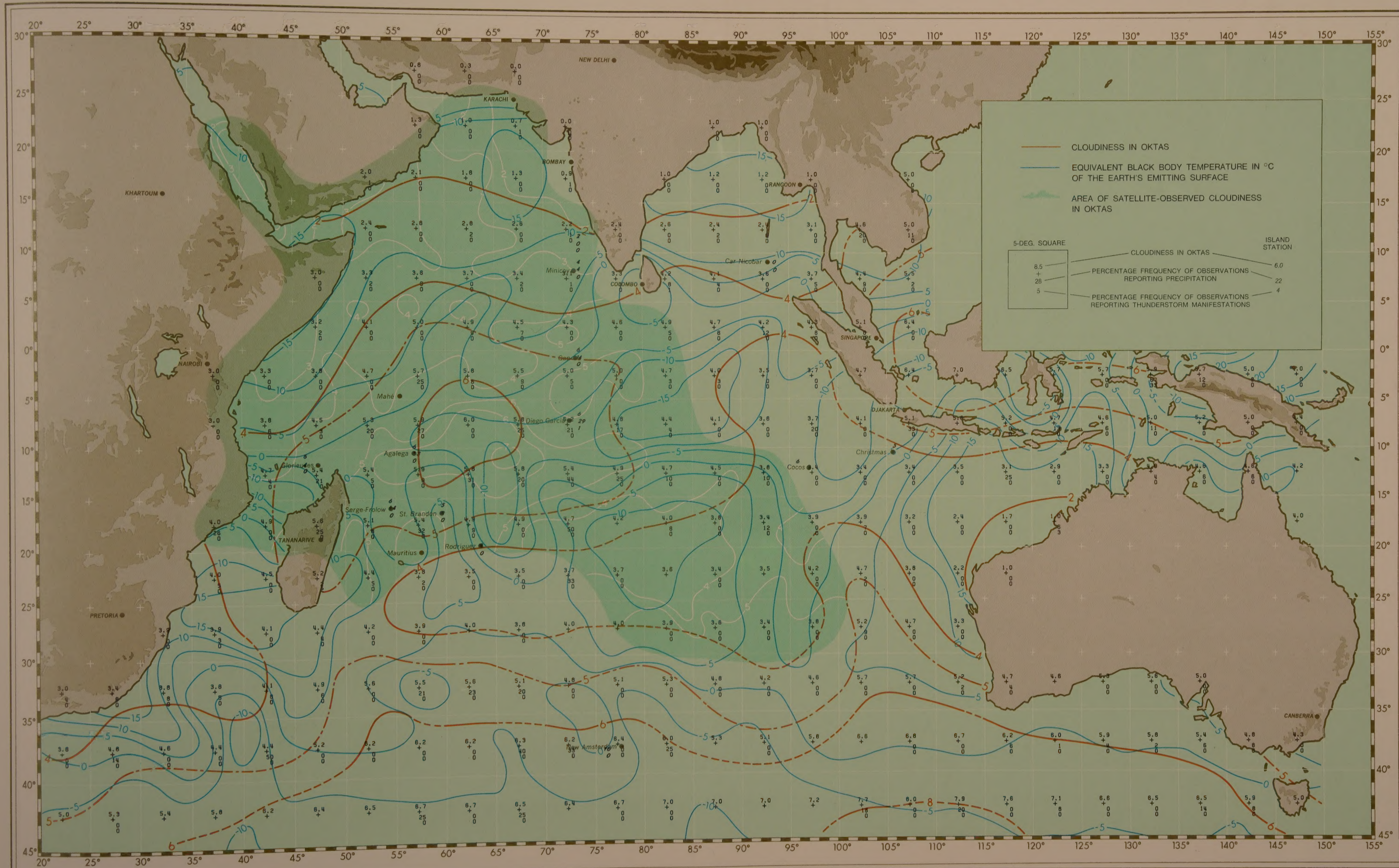


# CLOUDS AND PRECIPITATION January 1964 Chart 109



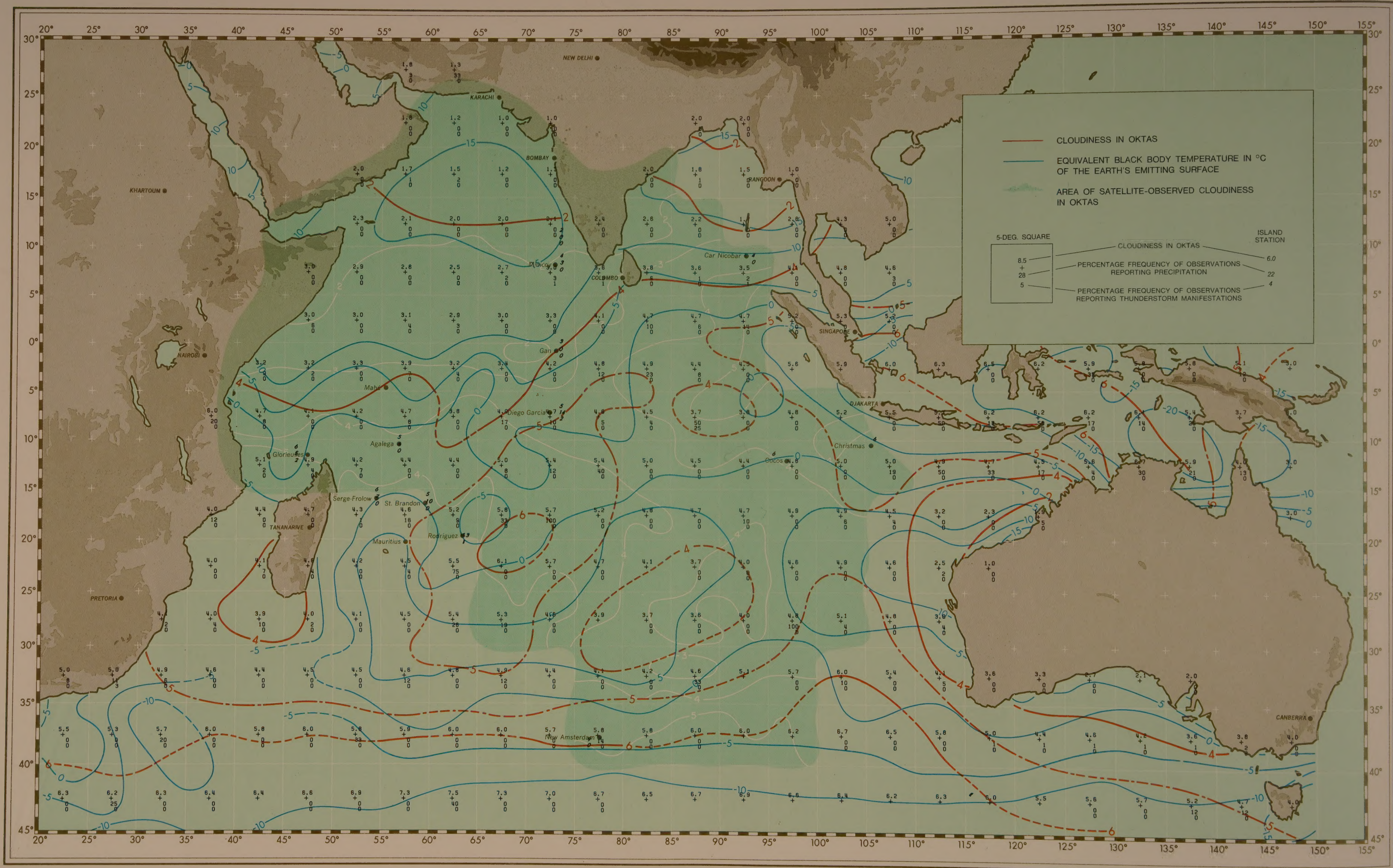


# CLOUDS AND PRECIPITATION February 1964 Chart 110



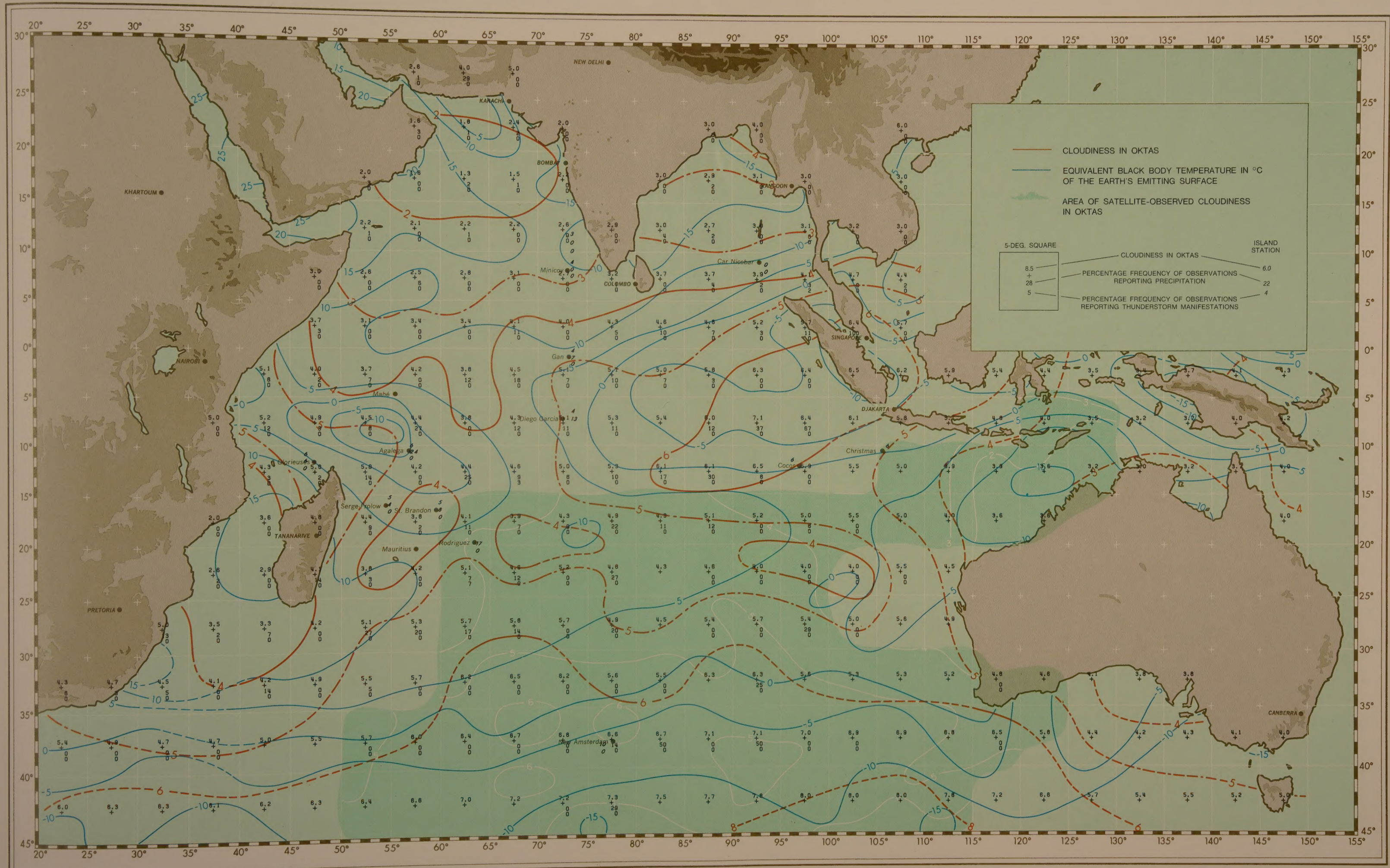


# CLOUDS AND PRECIPITATION March 1964 Chart 111



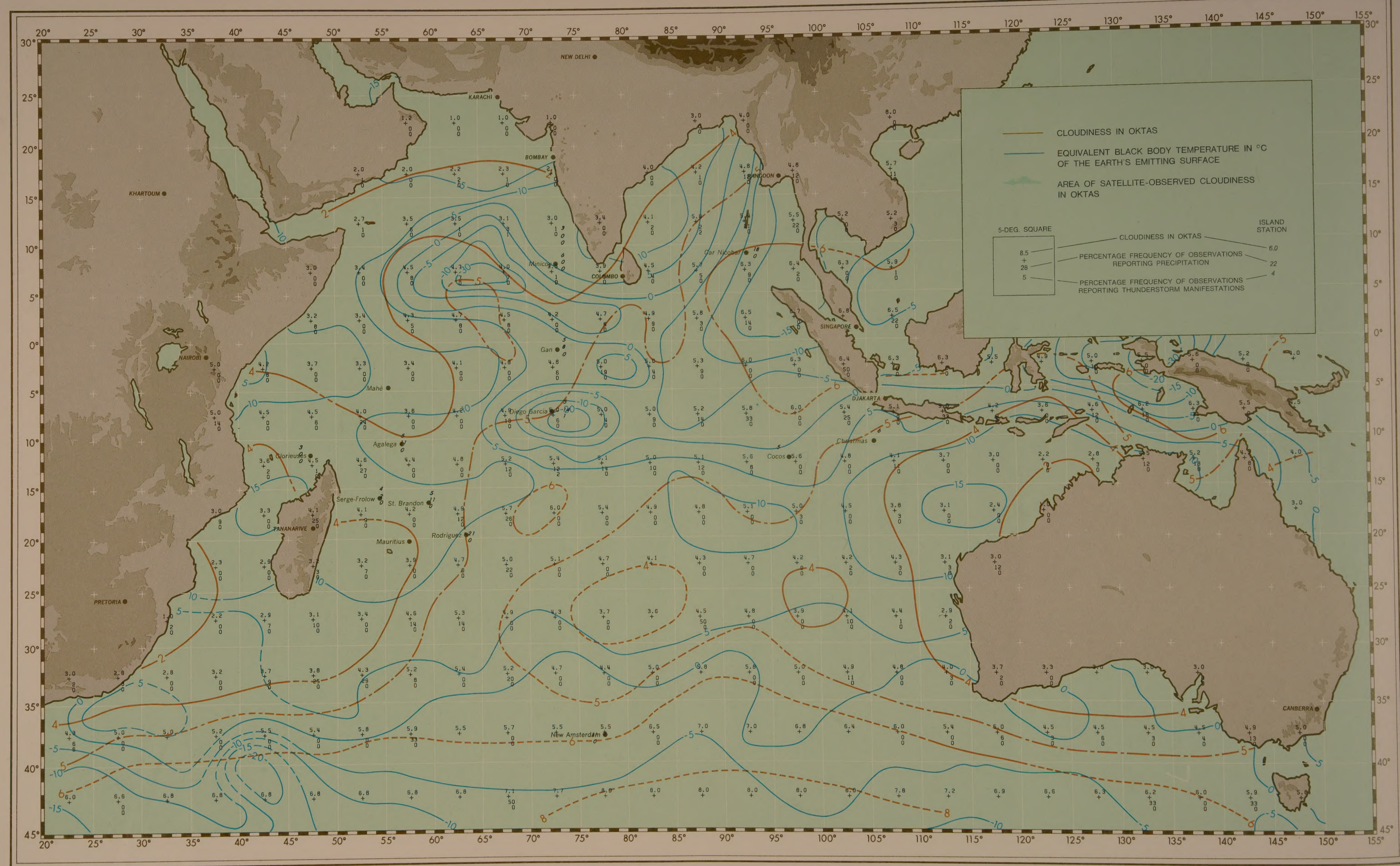


# CLOUDS AND PRECIPITATION April 1964 Chart 112



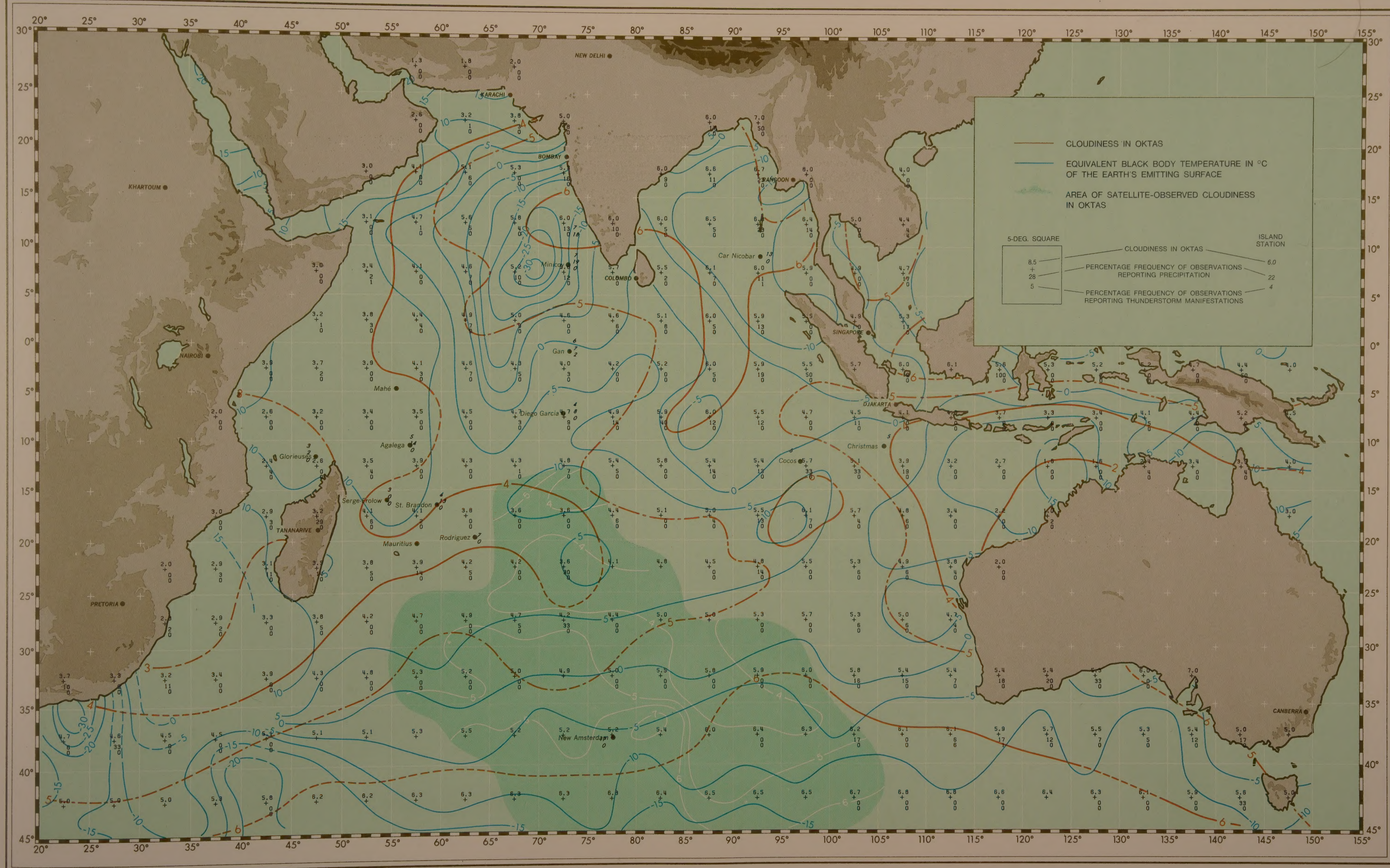


# CLOUDS AND PRECIPITATION May 1964 Chart 113



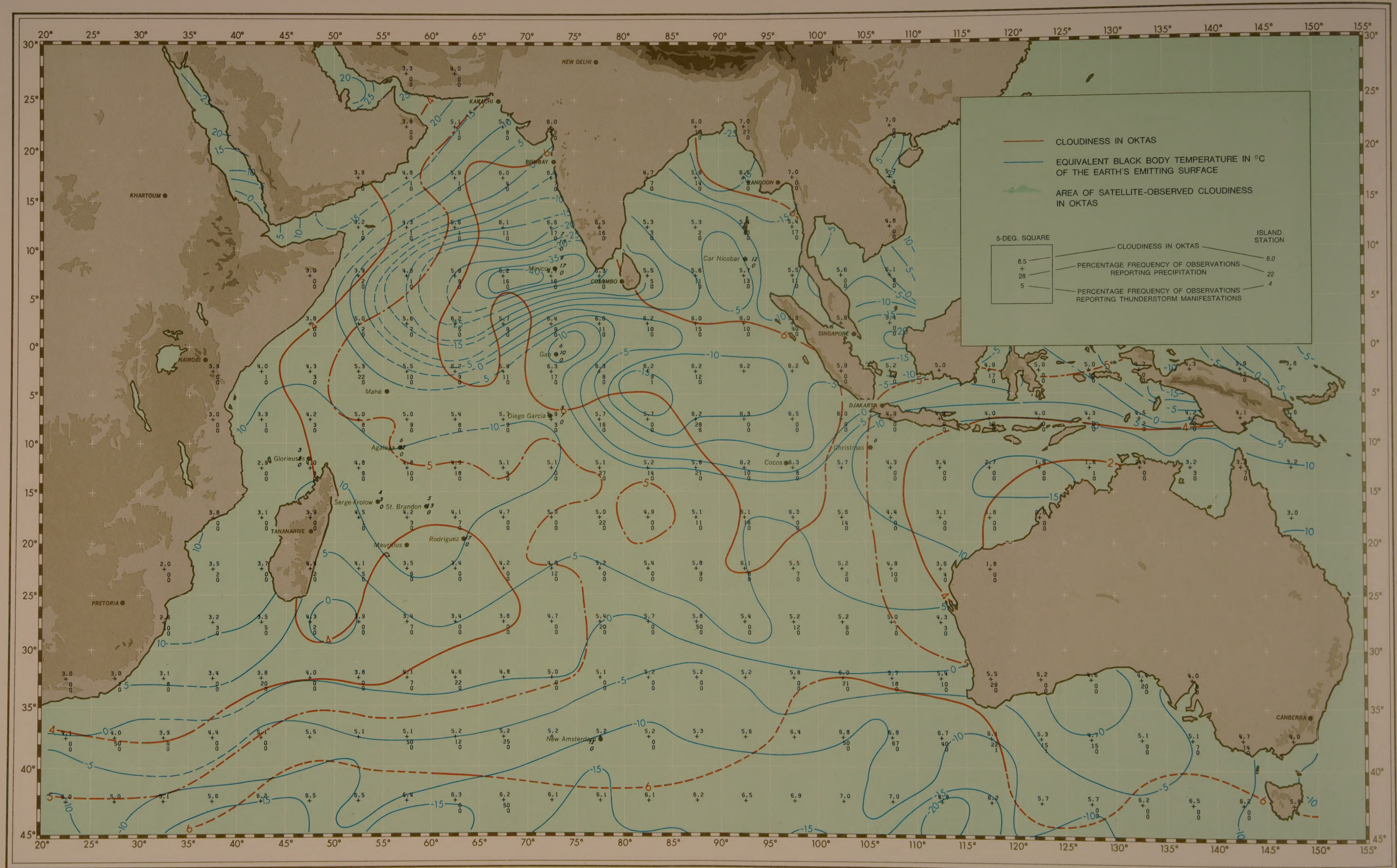


# CLOUDS AND PRECIPITATION June 1964 Chart 114



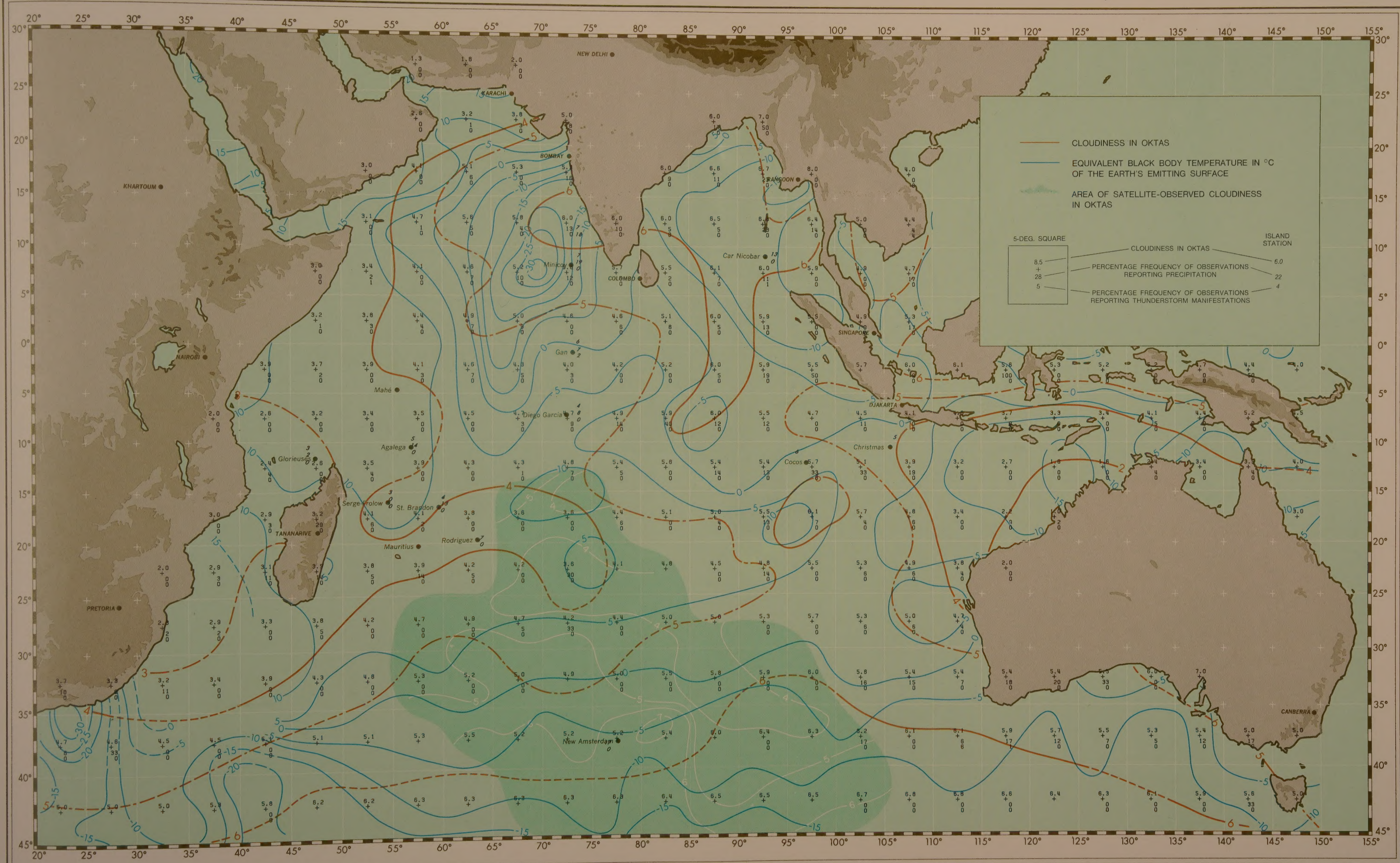


# CLOUDS AND PRECIPITATION July 1964 Chart 115



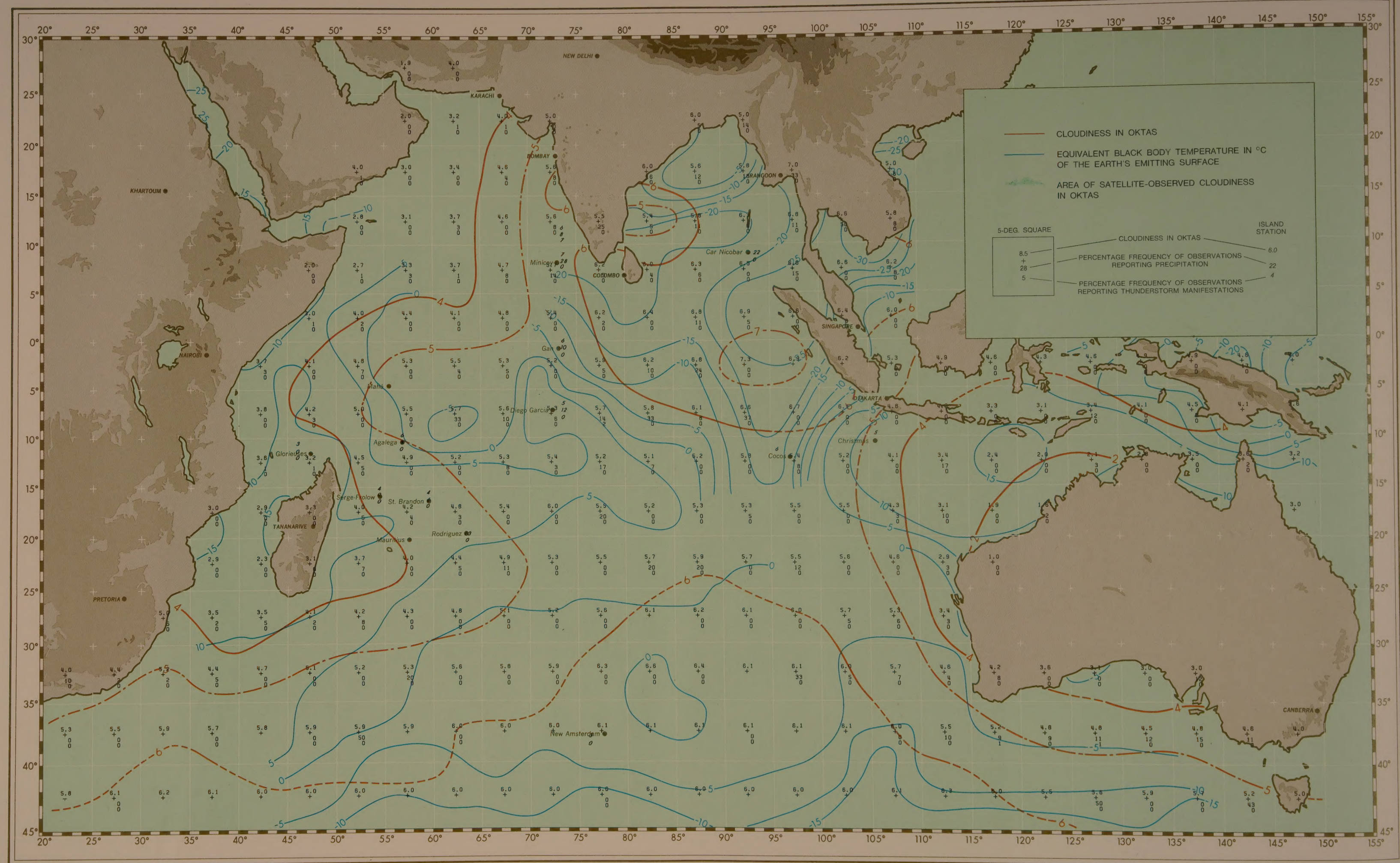


# CLOUDS AND PRECIPITATION June 1964 Chart 114



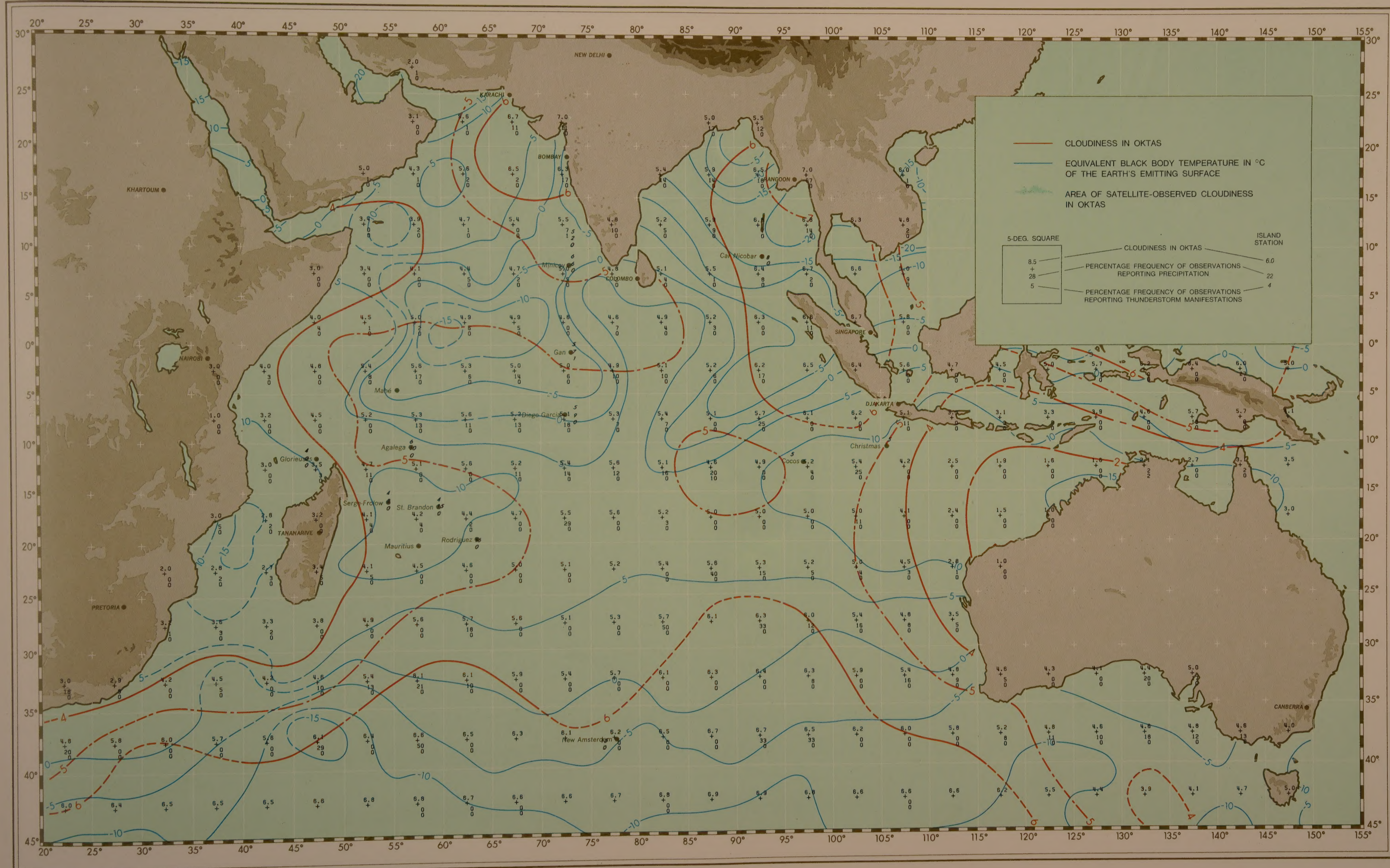


# CLOUDS AND PRECIPITATION September 1964 Chart 117





# CLOUDS AND PRECIPITATION August 1964 Chart 116

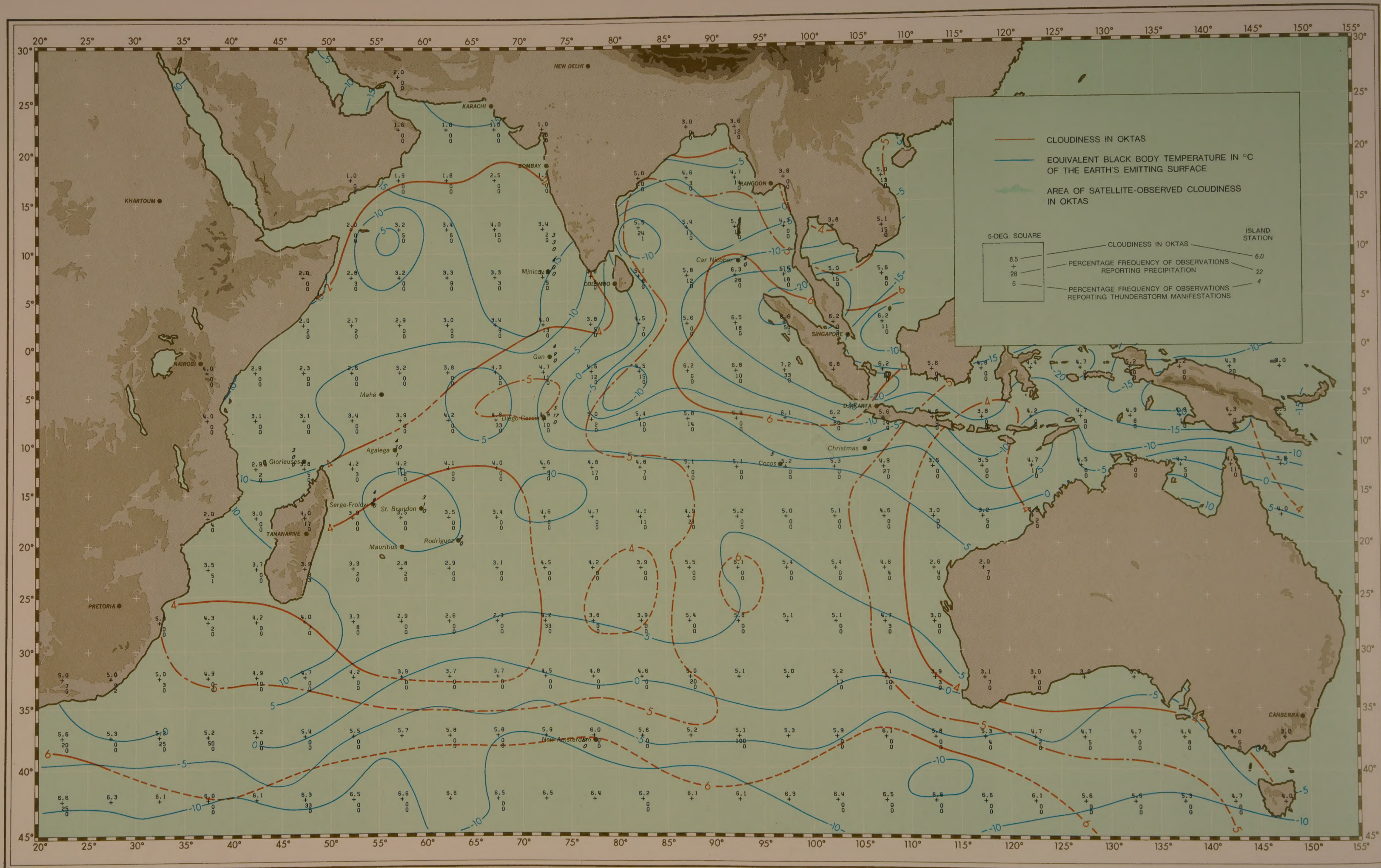




## CLOUDS AND PRECIPITATION

## November 1964

## Chart 119

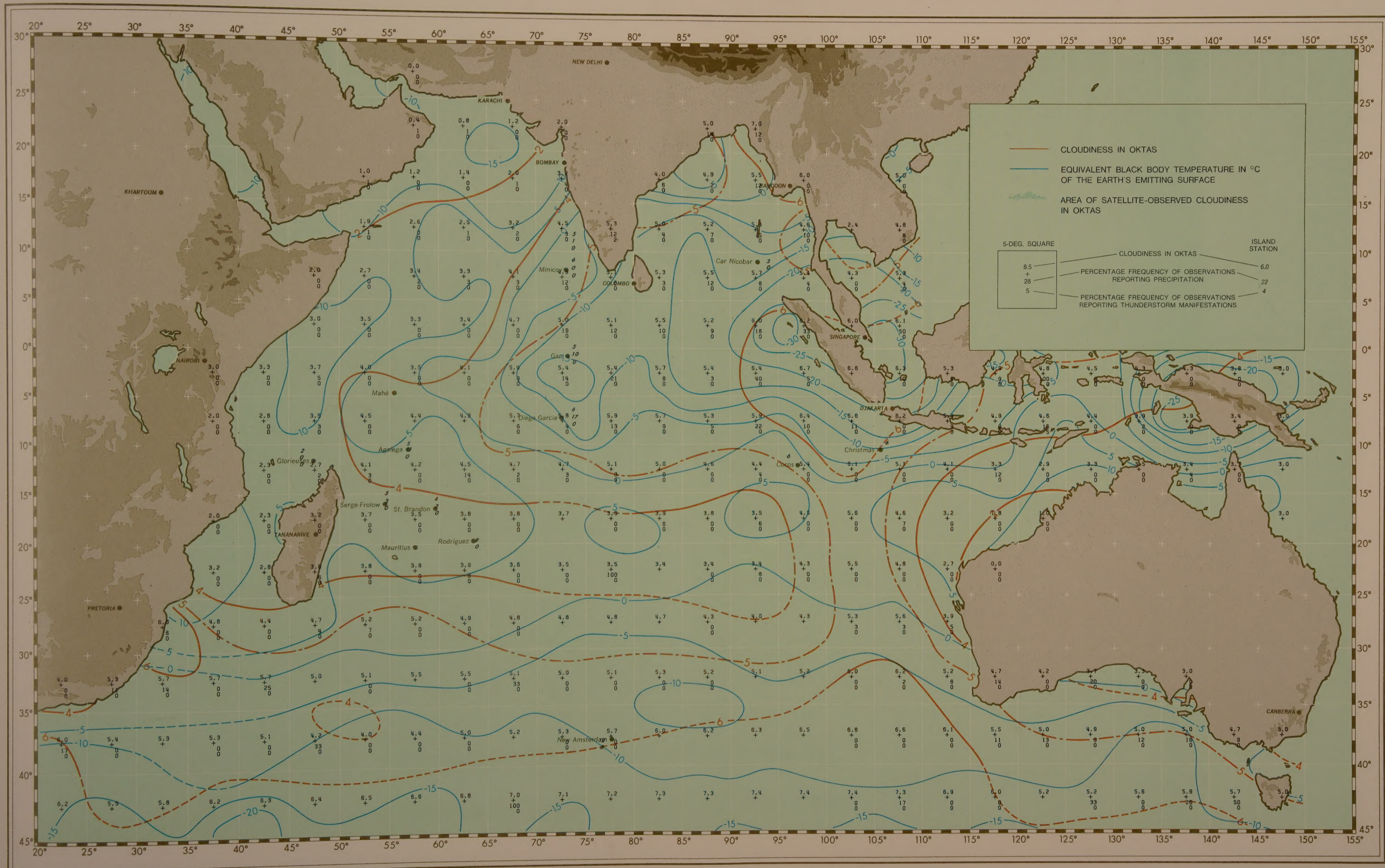




## CLOUDS AND PRECIPITATION

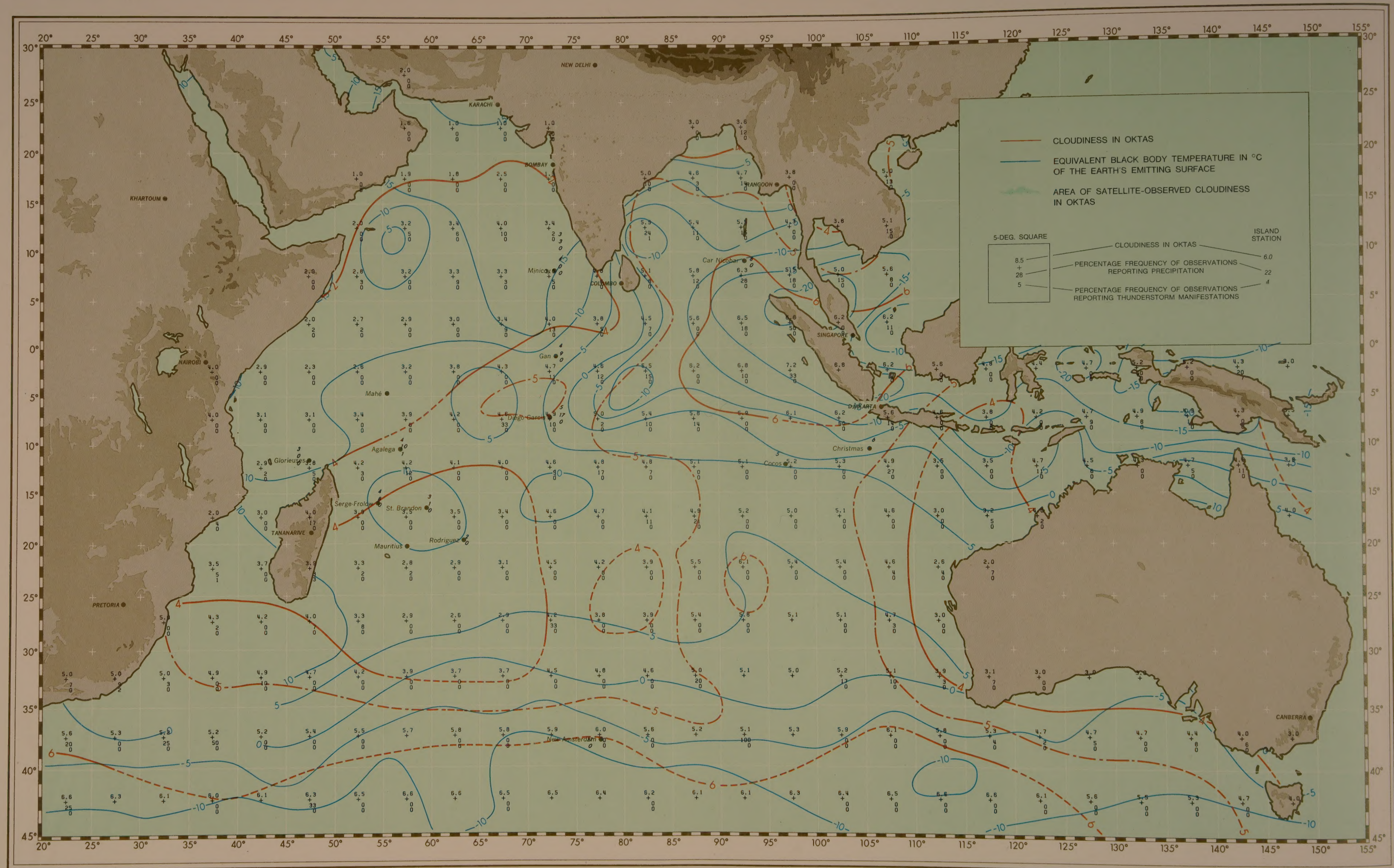
## October 1964

### Chart 118



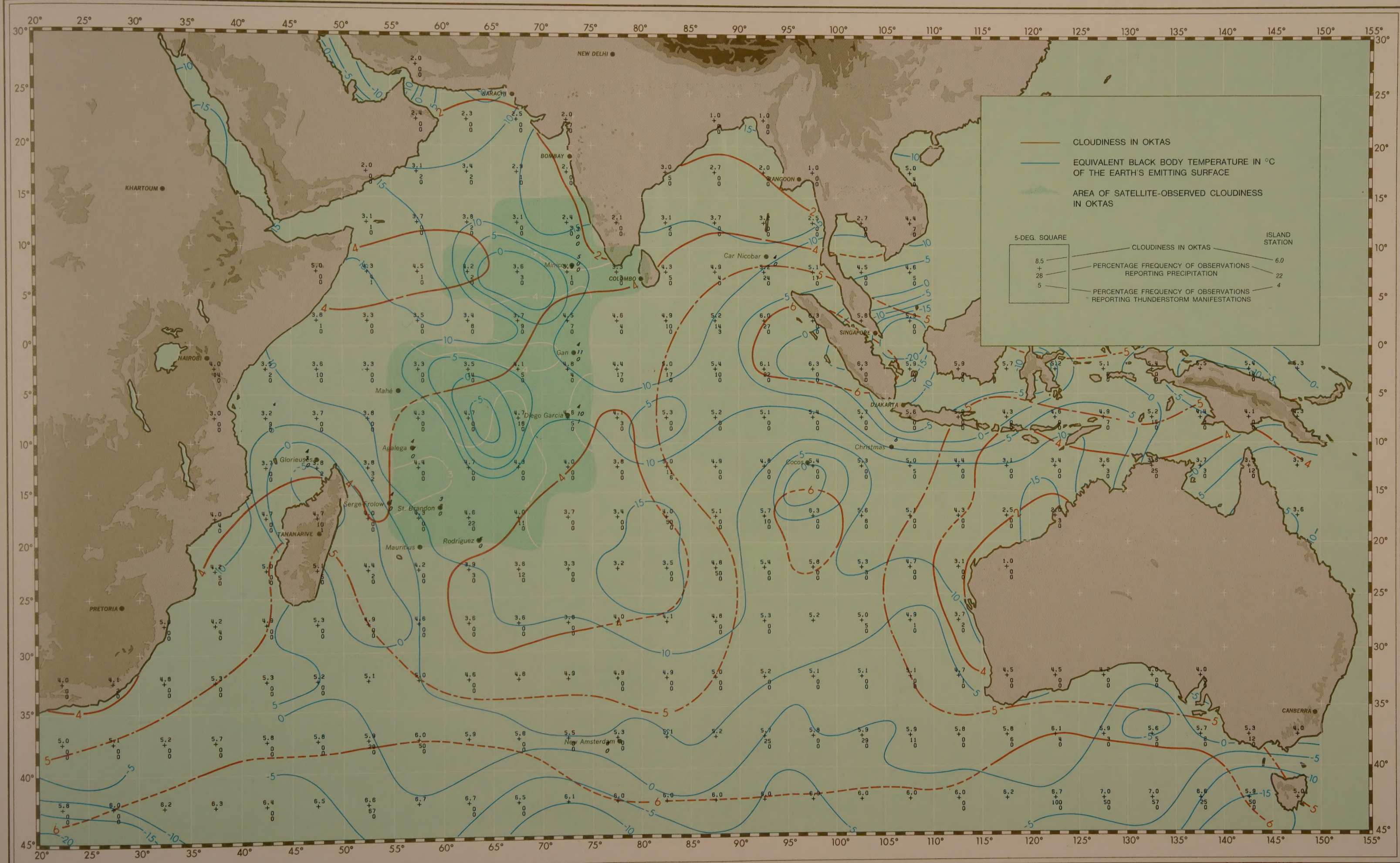


# CLOUDS AND PRECIPITATION November 1964 Chart 119





# CLOUDS AND PRECIPITATION December 1964 Chart 120





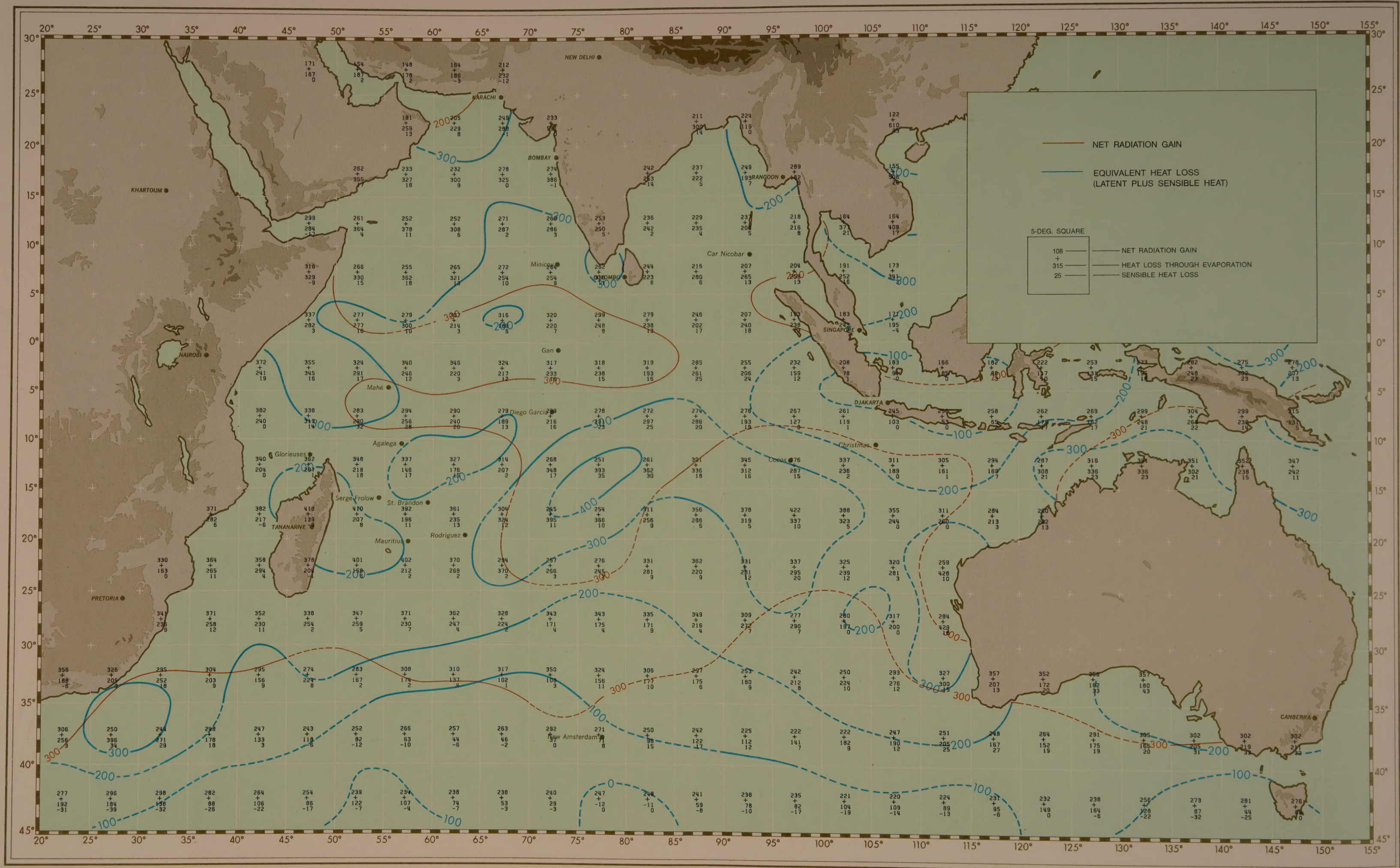
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# Heat Exchange at the Sea Surface

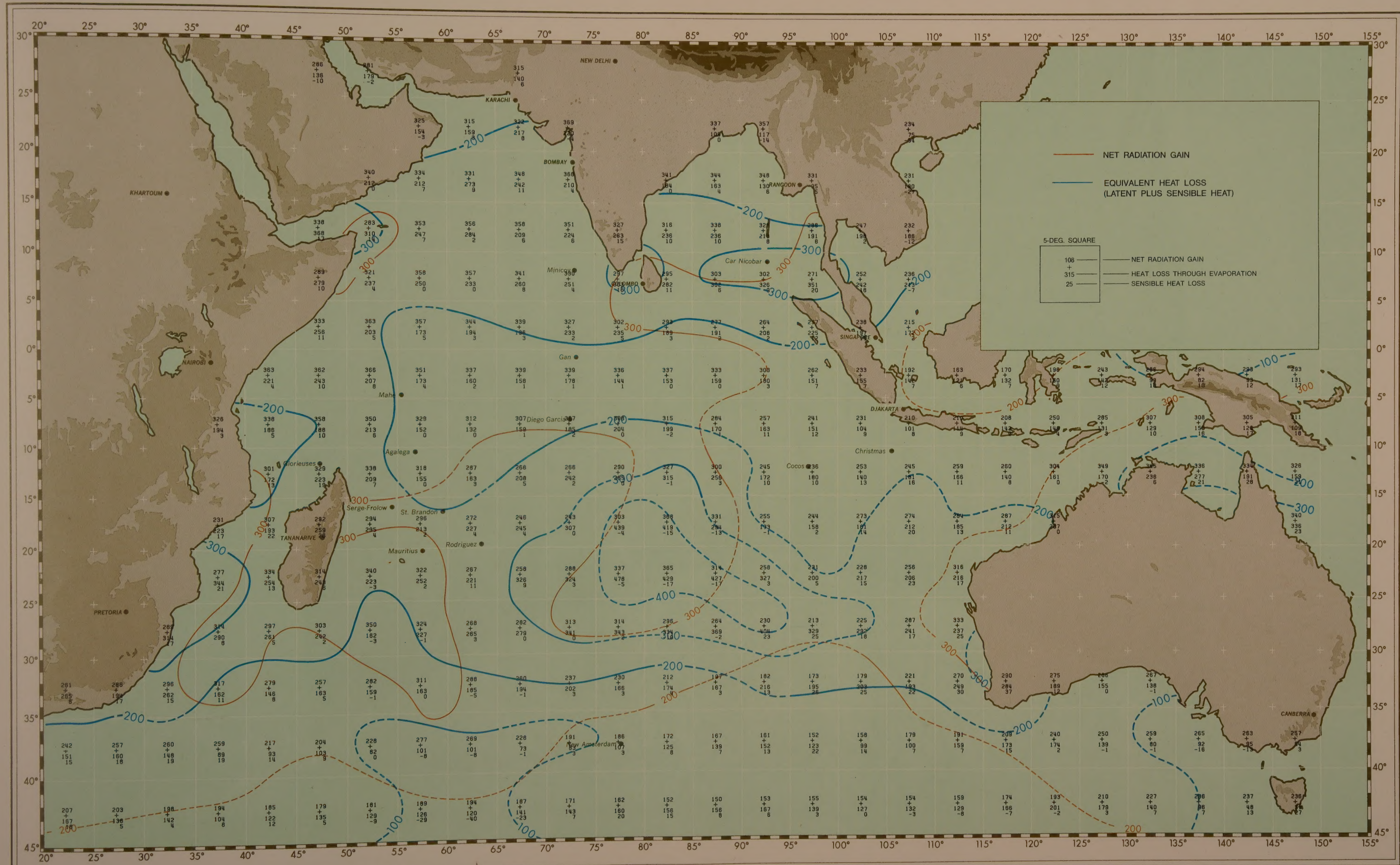


# HEAT EXCHANGE AT THE SEA SURFACE IN CAL CM<sup>-2</sup> DAY<sup>-1</sup> January 1963 Chart 121



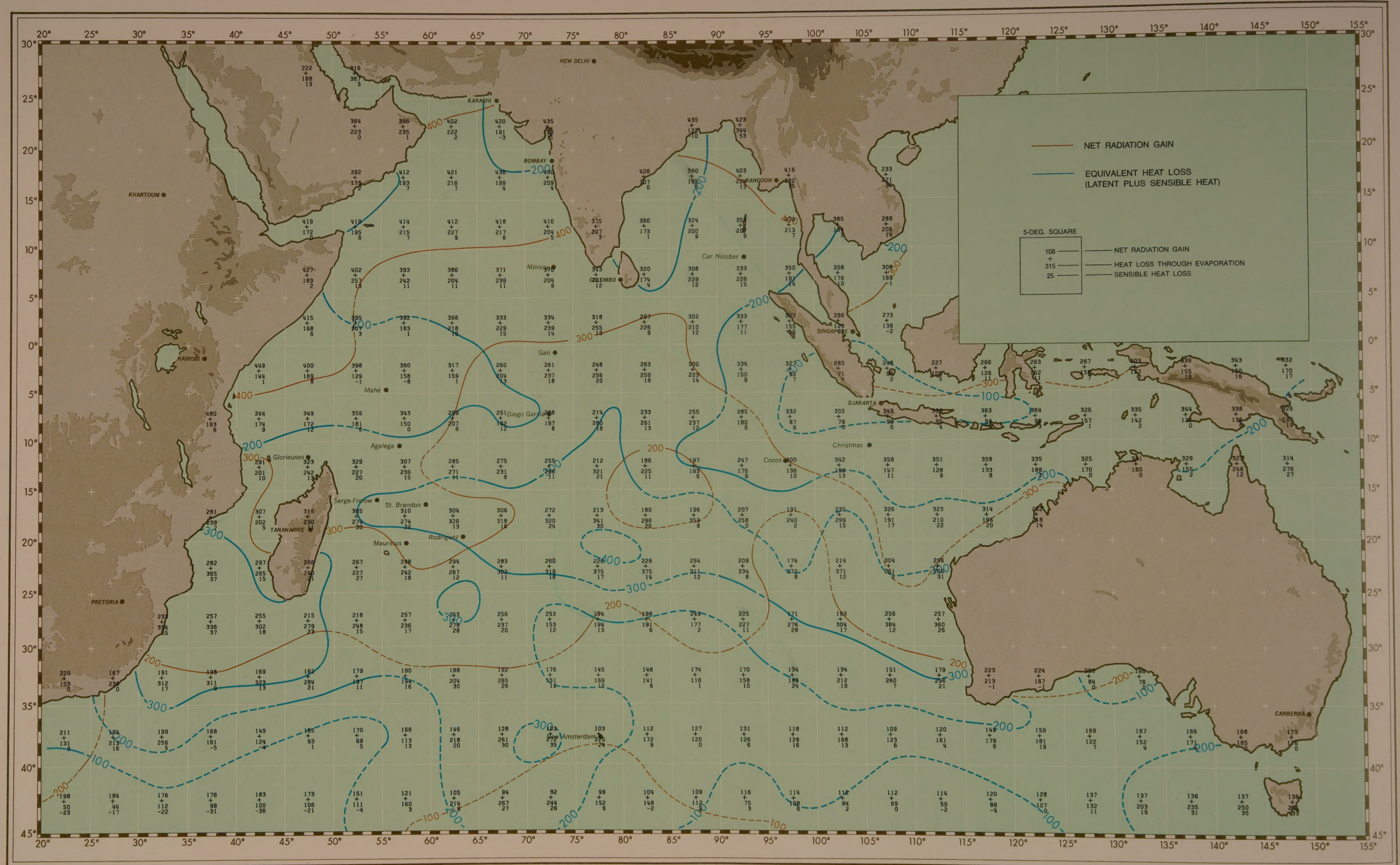


# HEAT EXCHANGE AT THE SEA SURFACE IN CAL CM<sup>-2</sup> DAY<sup>-1</sup> February 1963 Chart 122



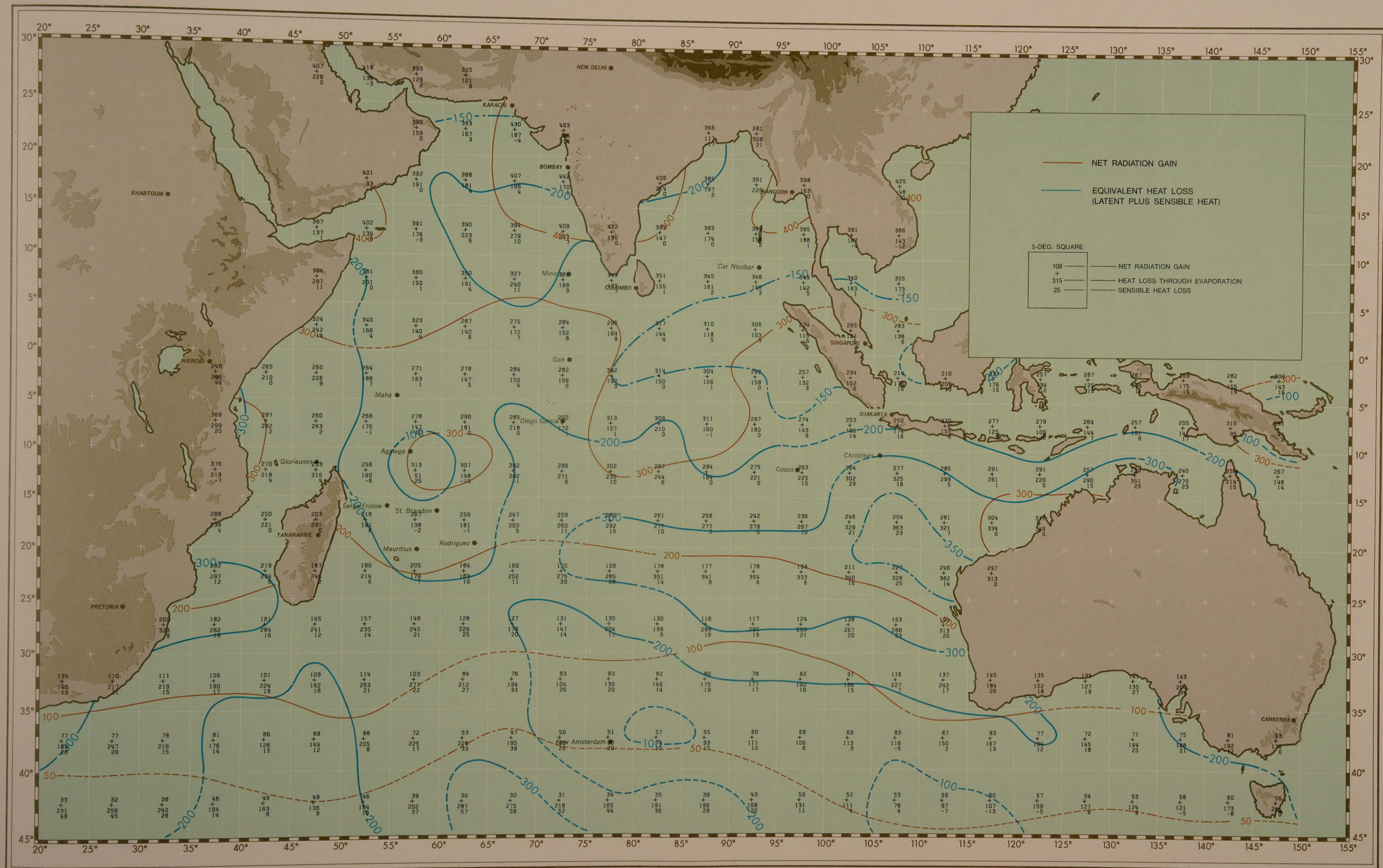


# HEAT EXCHANGE AT THE SEA SURFACE IN CAL CM<sup>-2</sup> DAY<sup>-1</sup> March 1963 Chart 123



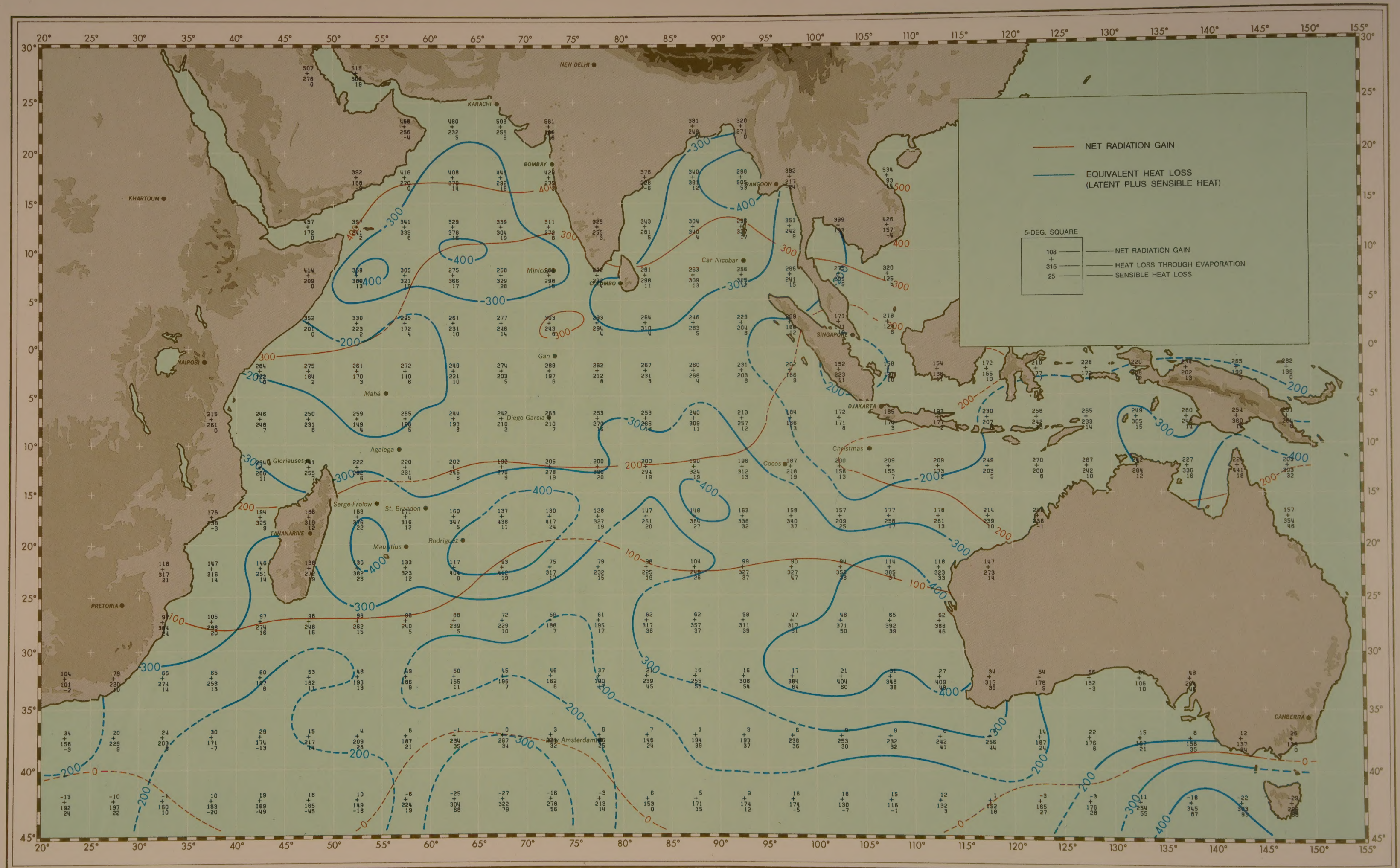


# HEAT EXCHANGE AT THE SEA SURFACE IN CAL CM<sup>-2</sup> DAY<sup>-1</sup> April 1963 Chart 124



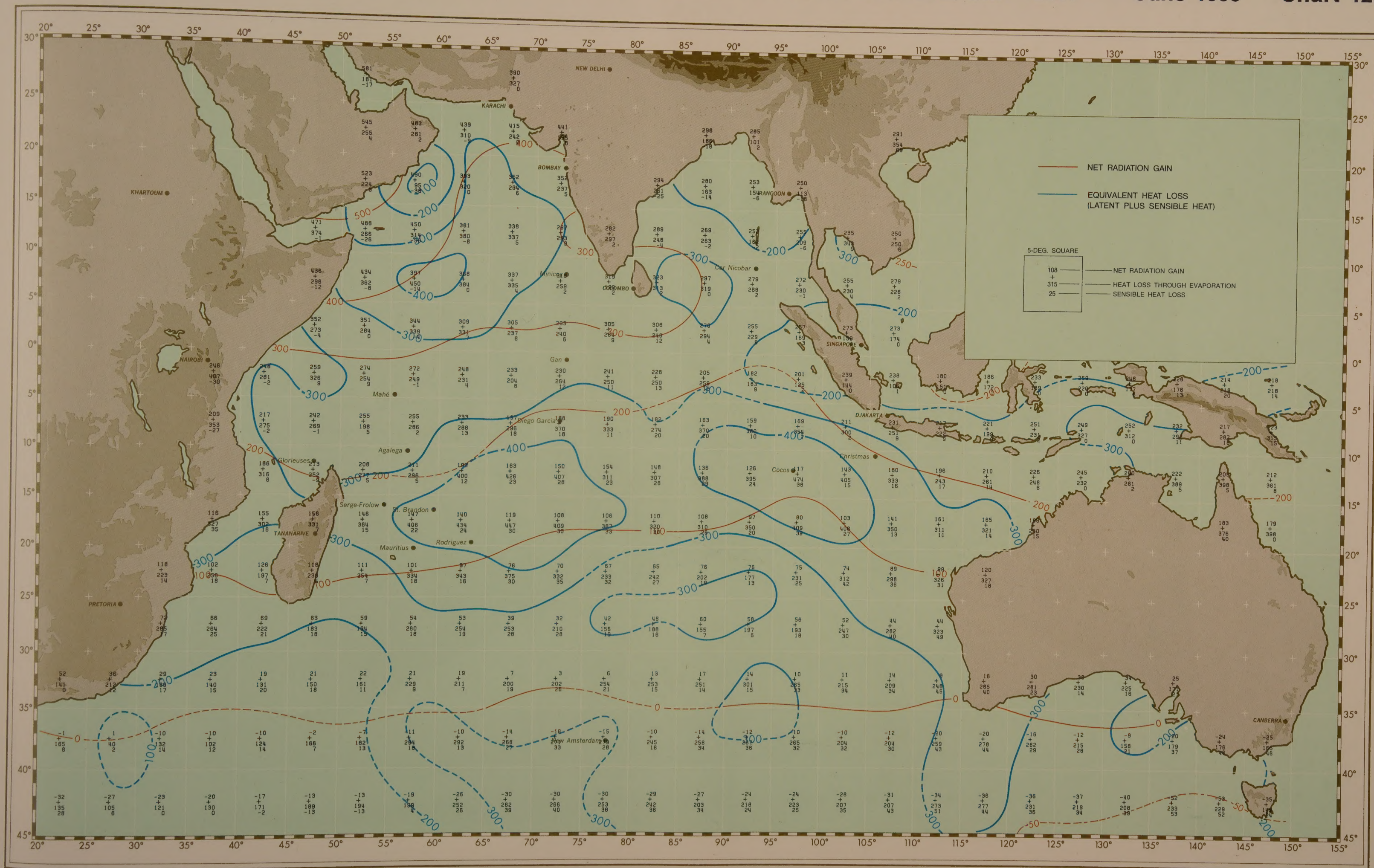


# HEAT EXCHANGE AT THE SEA SURFACE IN CAL CM<sup>-2</sup> DAY<sup>-1</sup> May 1963 Chart 125



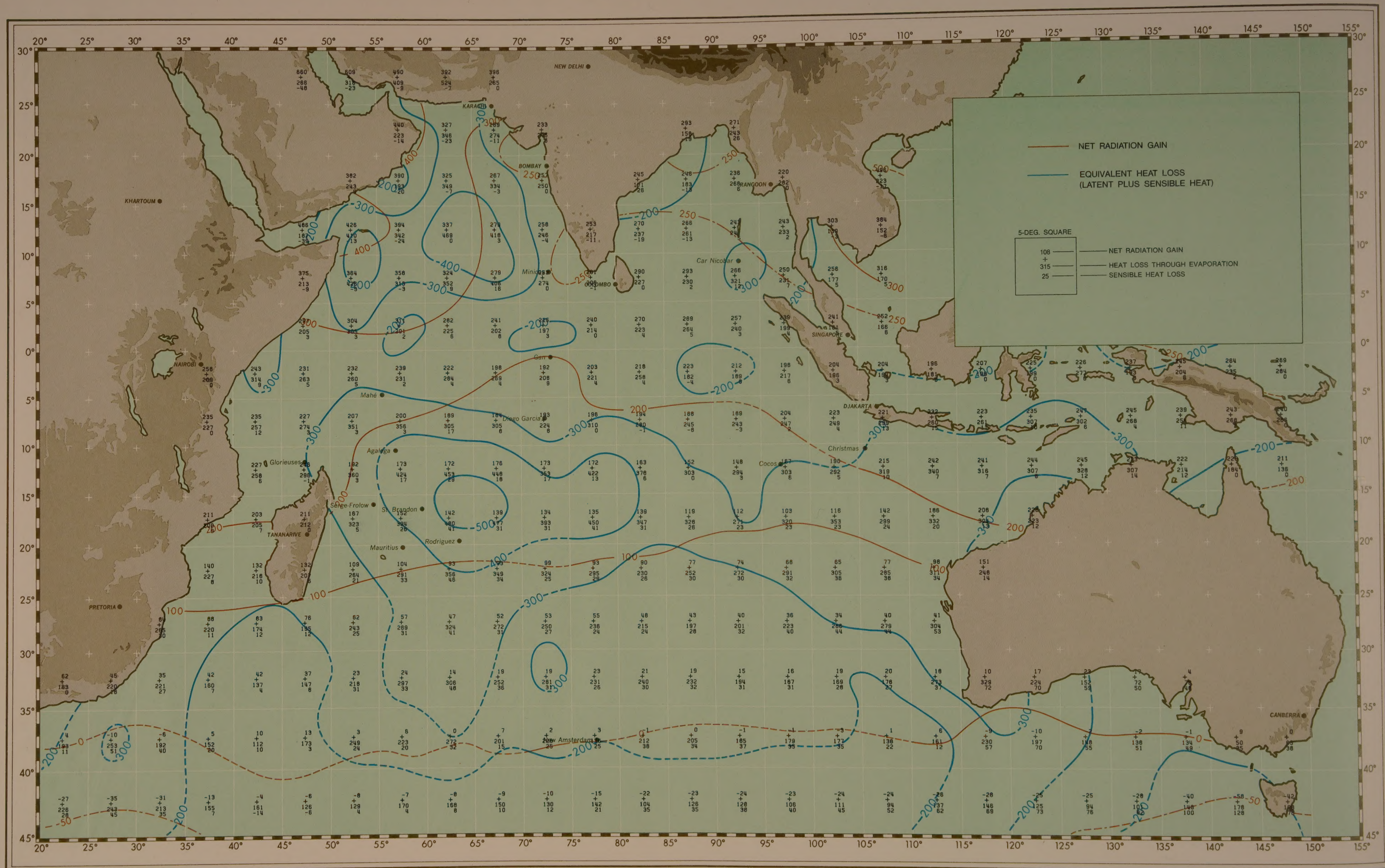


# HEAT EXCHANGE AT THE SEA SURFACE IN CAL CM<sup>-2</sup> DAY<sup>-1</sup> June 1963 Chart 126



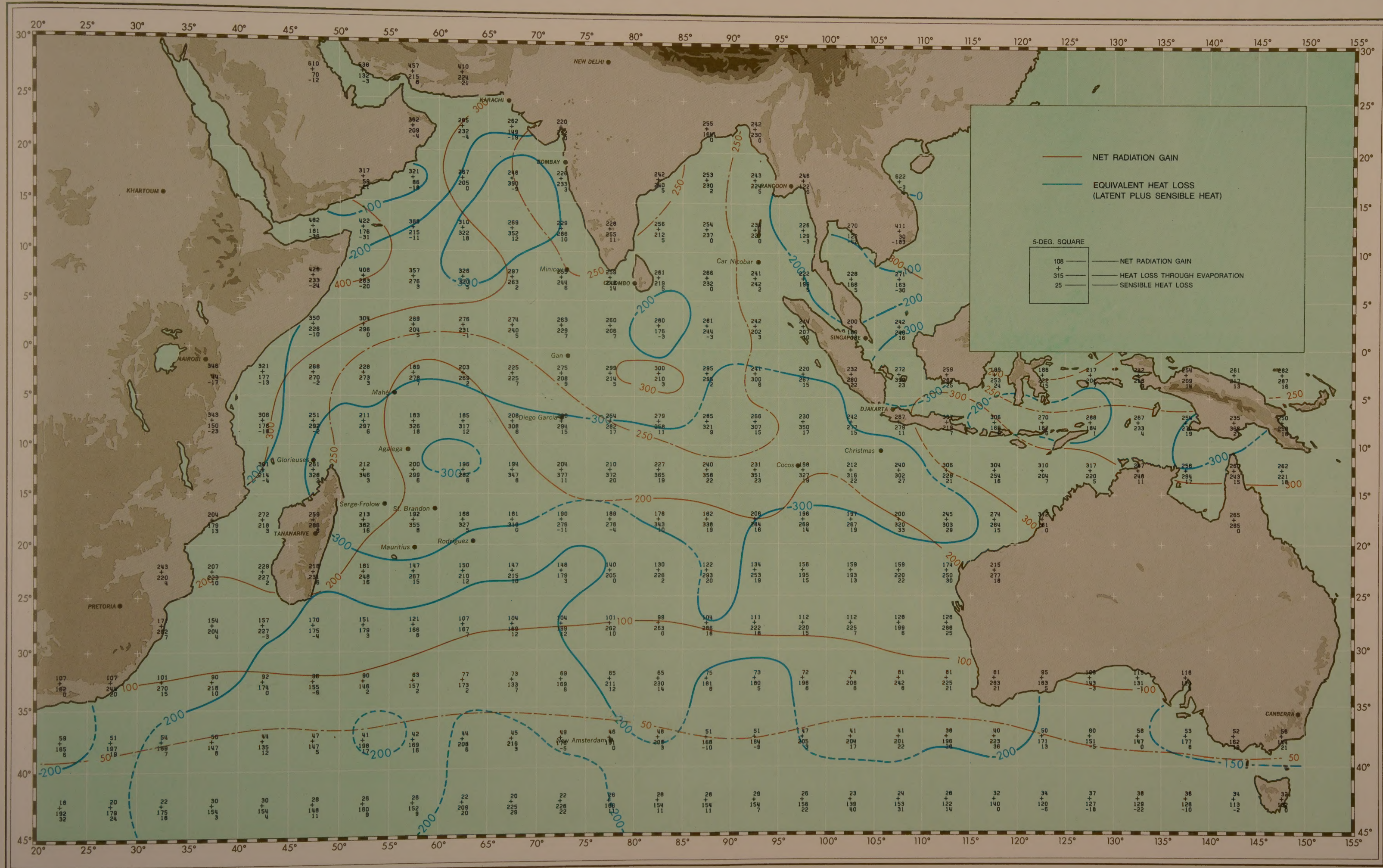


# HEAT EXCHANGE AT THE SEA SURFACE IN CAL CM<sup>-2</sup> DAY<sup>-1</sup> July 1963 Chart 127



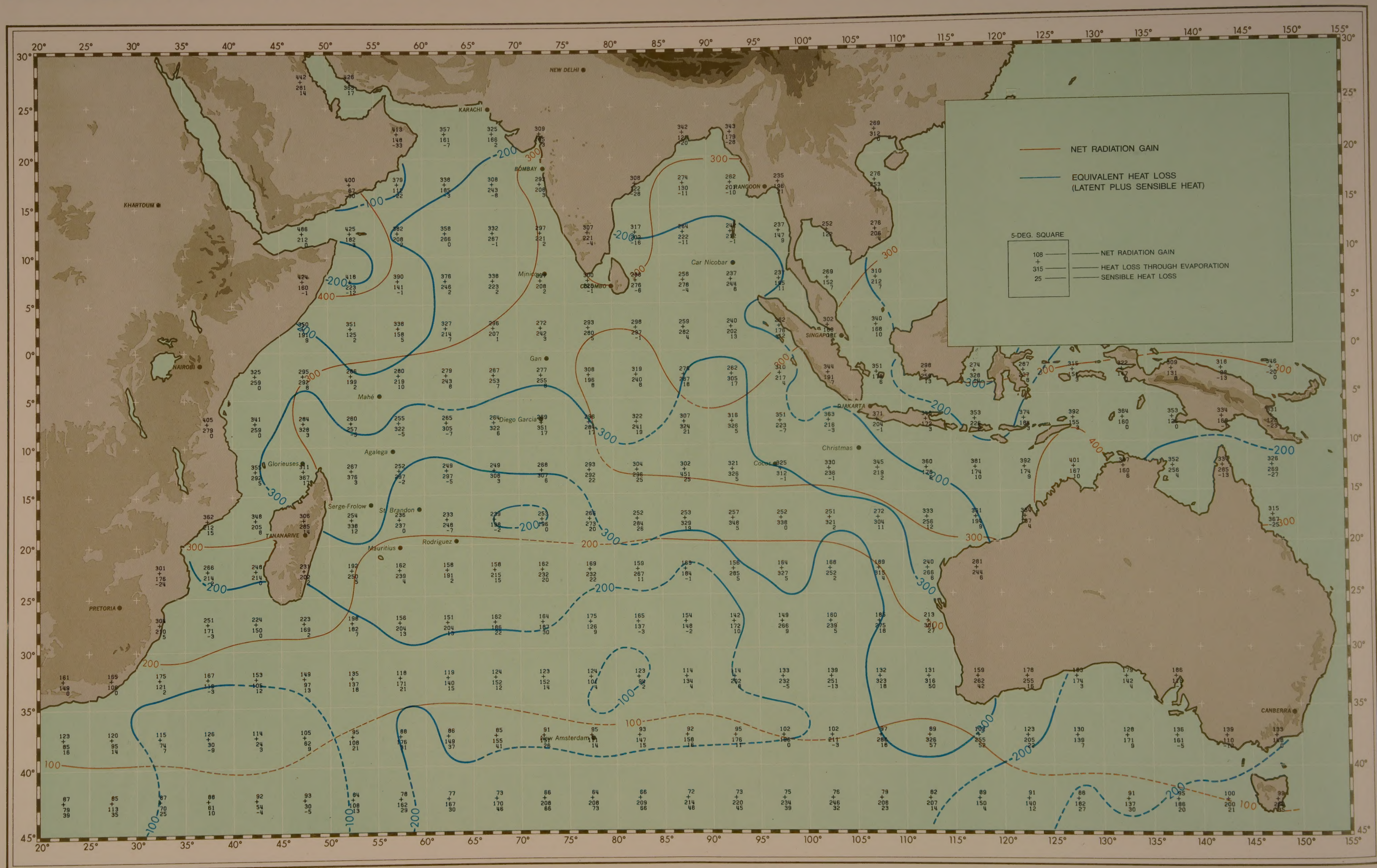


### Chart 128



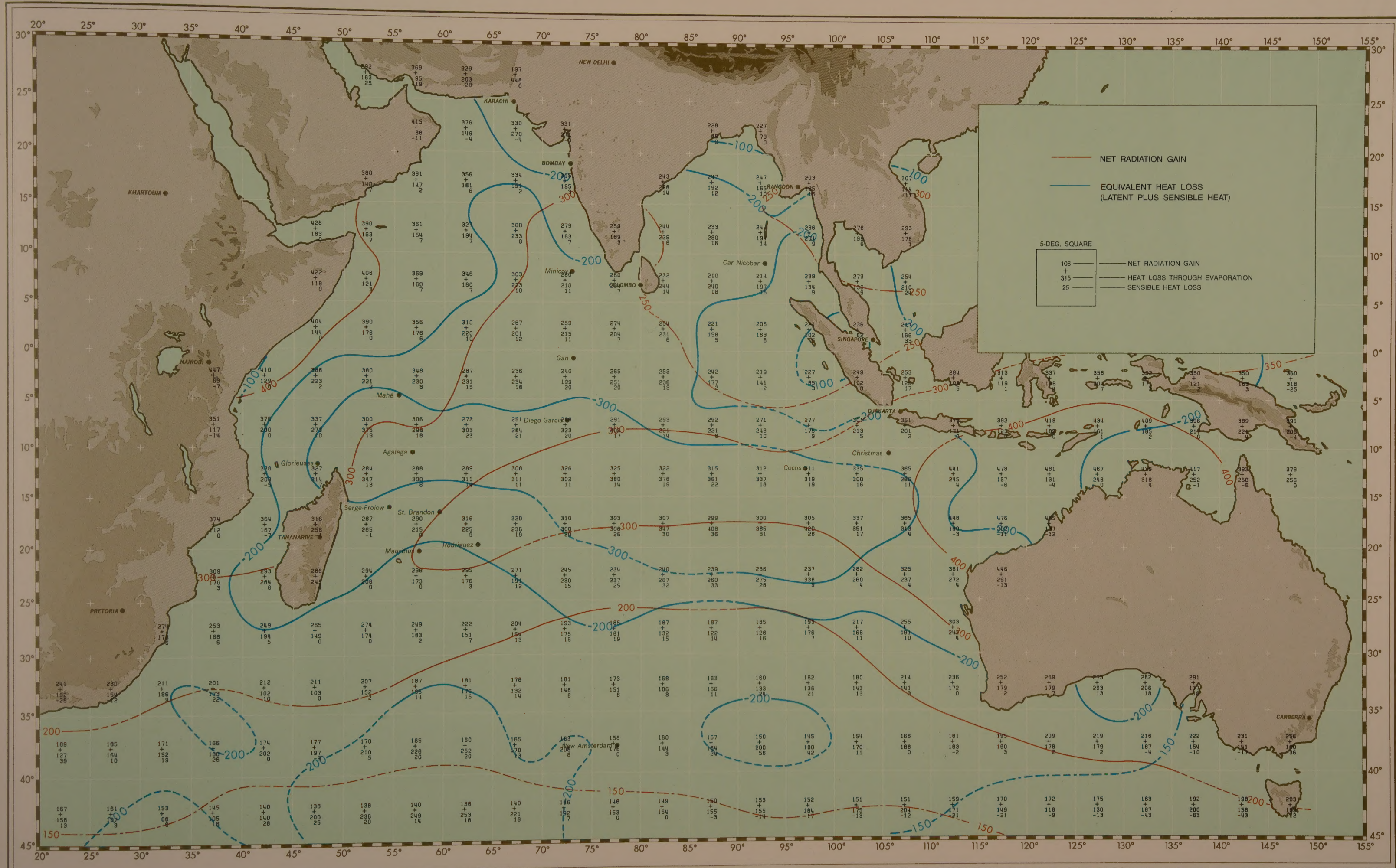


# HEAT EXCHANGE AT THE SEA SURFACE IN CAL CM<sup>-2</sup> DAY<sup>-1</sup> September 1963 Chart 129



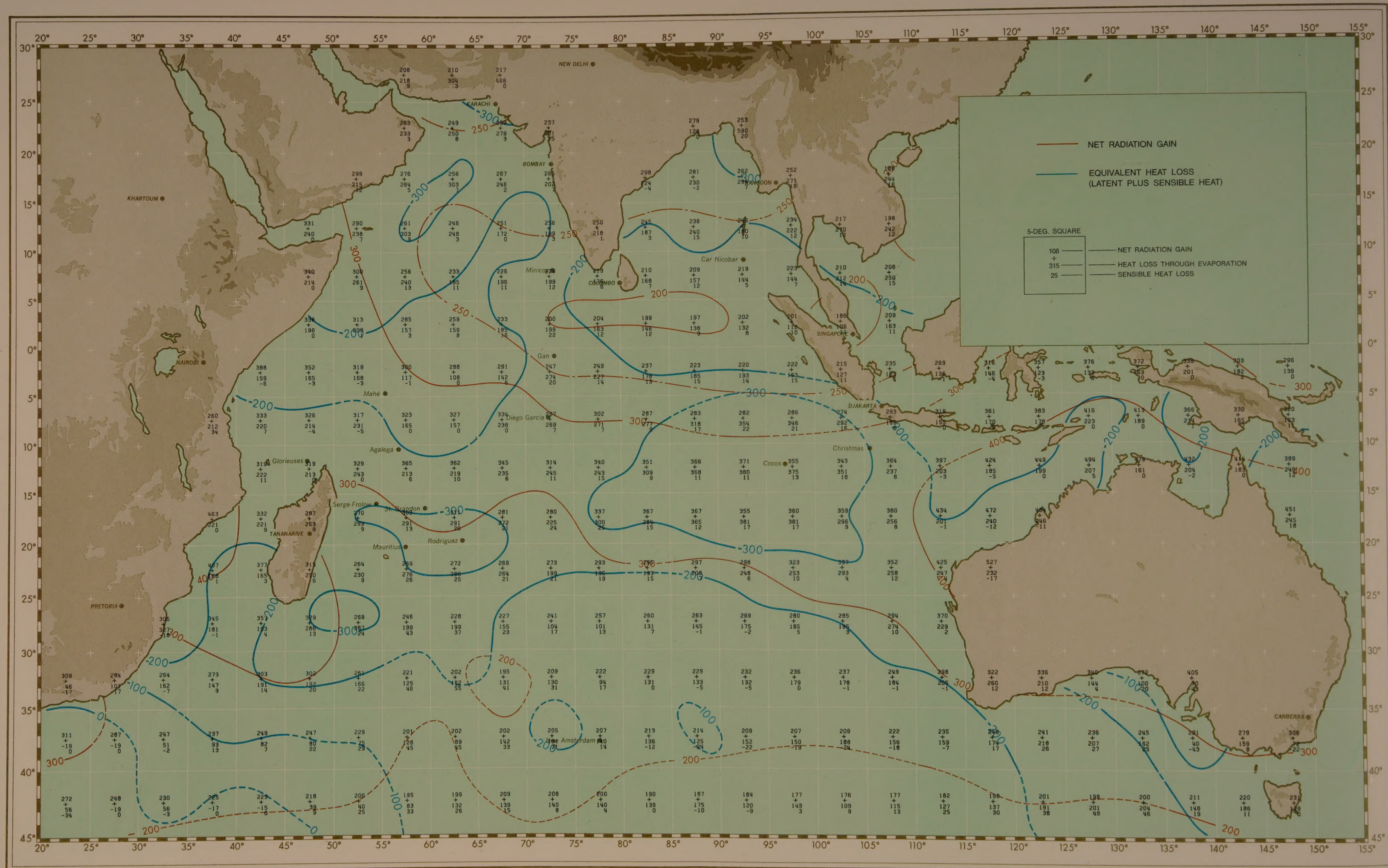


# HEAT EXCHANGE AT THE SEA SURFACE IN CAL CM<sup>-2</sup> DAY<sup>-1</sup> October 1963 Chart 130



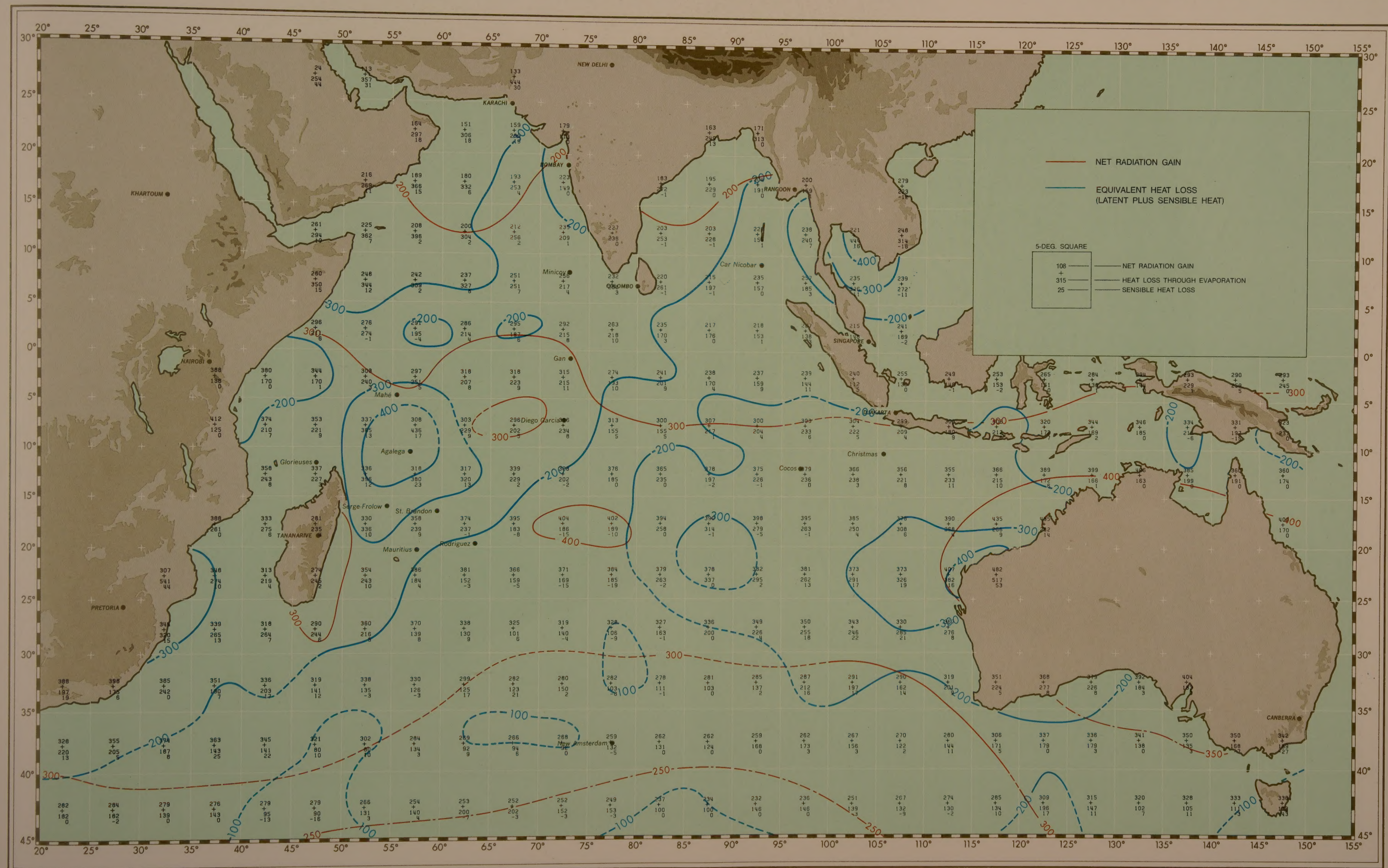


## November 1963      Chart 131



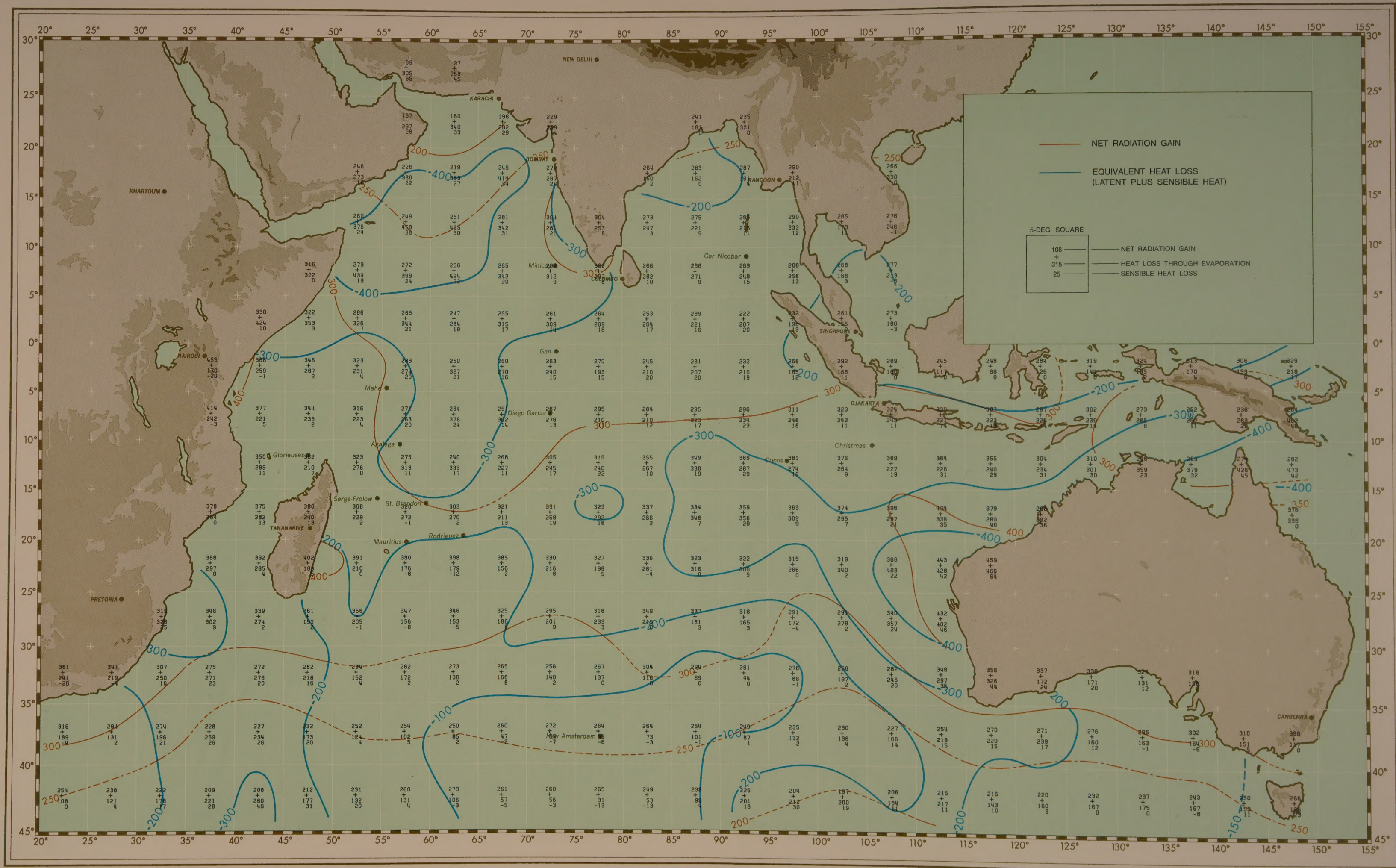


# HEAT EXCHANGE AT THE SEA SURFACE IN CAL CM<sup>-2</sup> DAY<sup>-1</sup> December 1963 Chart 132



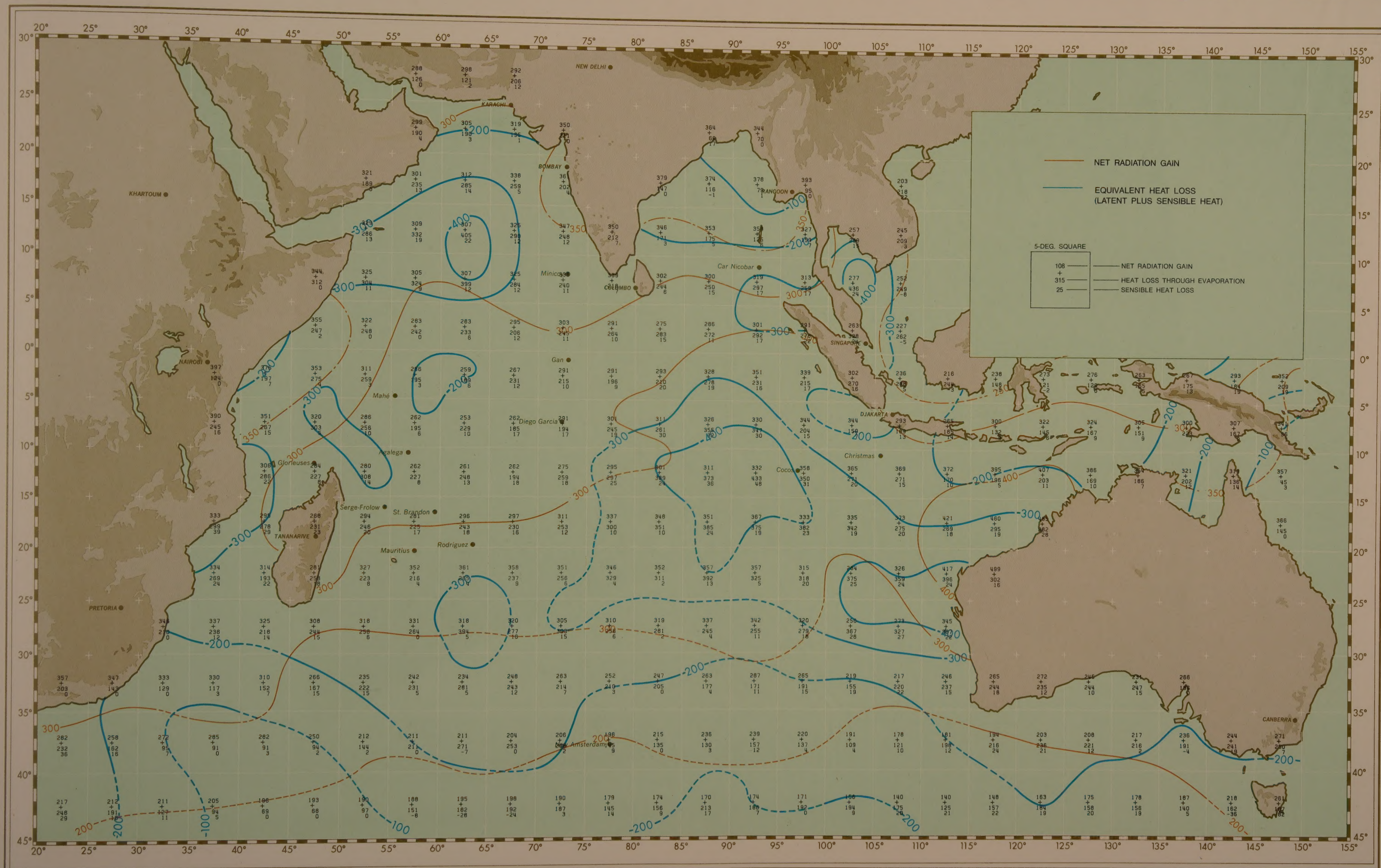


## Chart 133



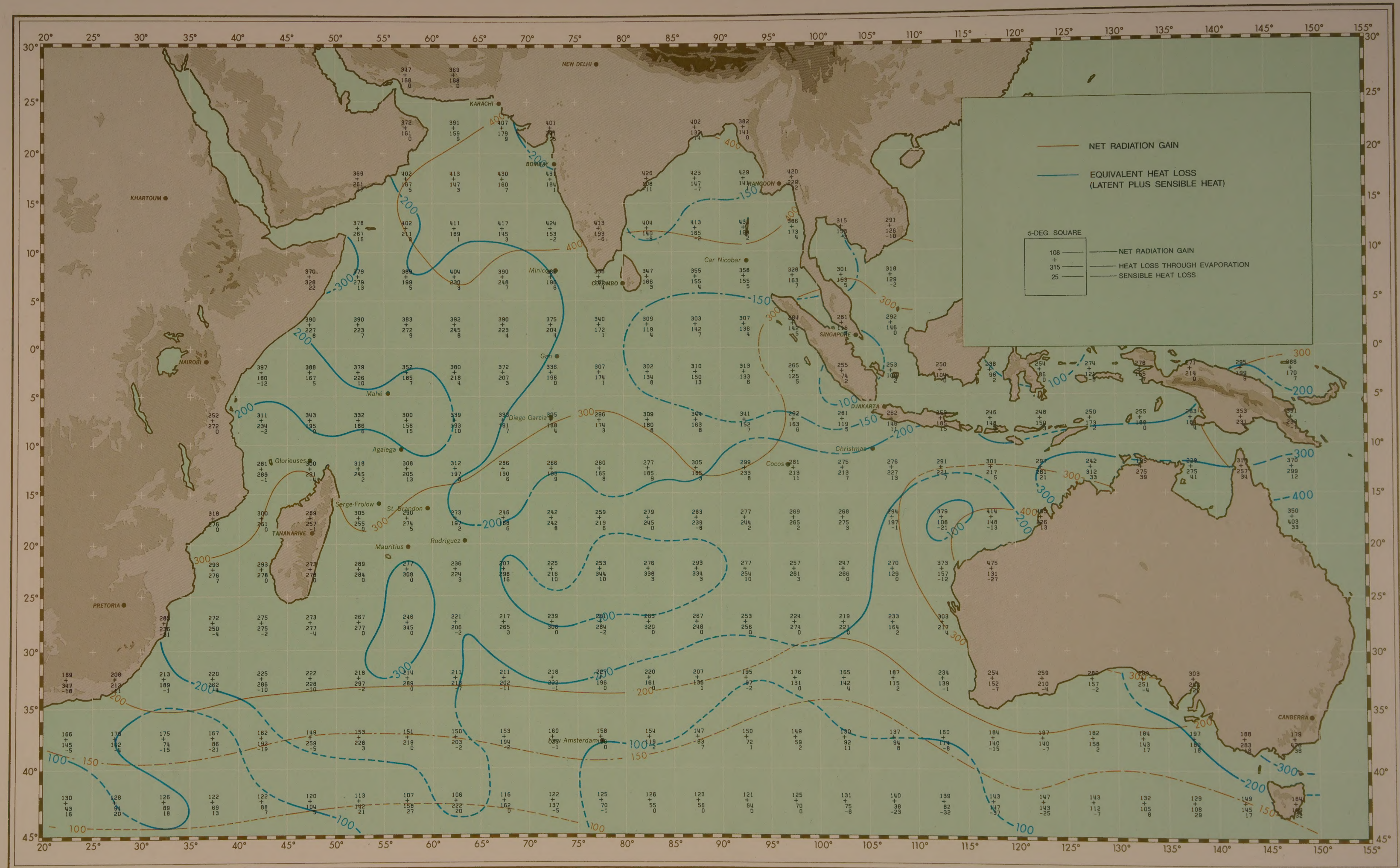


# HEAT EXCHANGE AT THE SEA SURFACE IN CAL CM<sup>-2</sup> DAY<sup>-1</sup> February 1964 Chart 134



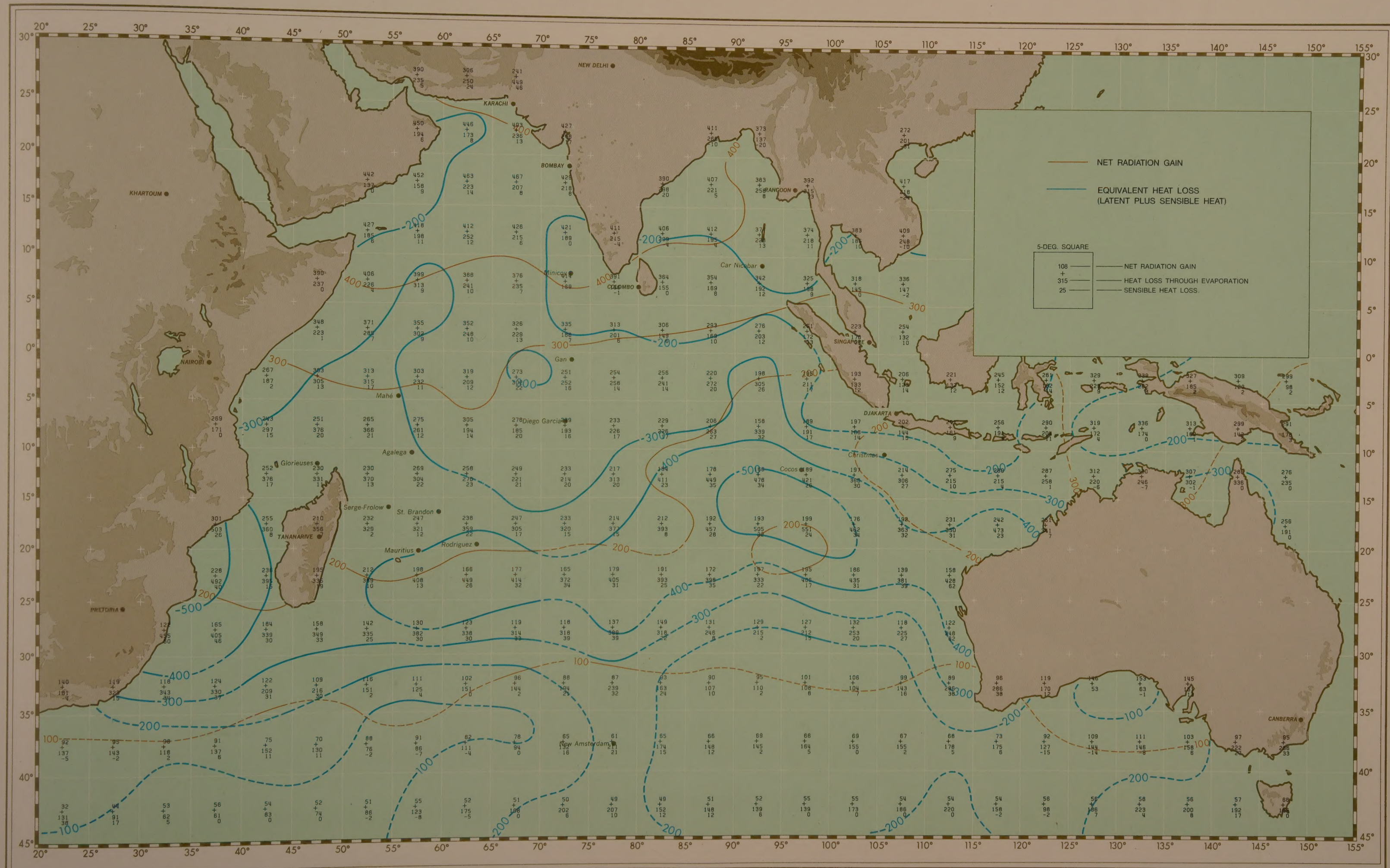


# HEAT EXCHANGE AT THE SEA SURFACE IN CAL CM<sup>-2</sup> DAY<sup>-1</sup> March 1964 Chart 135



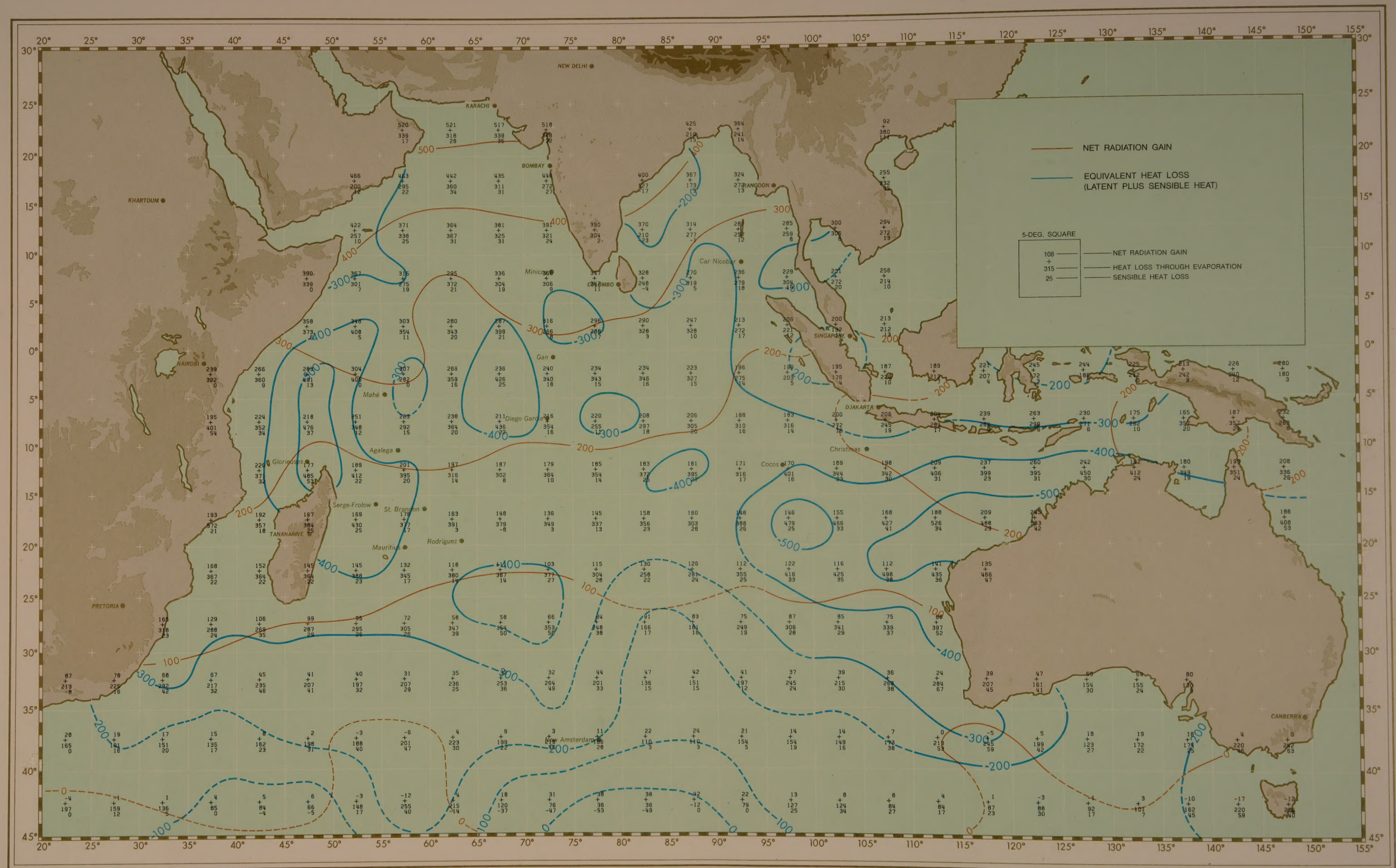


# HEAT EXCHANGE AT THE SEA SURFACE IN CAL CM<sup>-2</sup> DAY<sup>-1</sup> April 1964 Chart 136



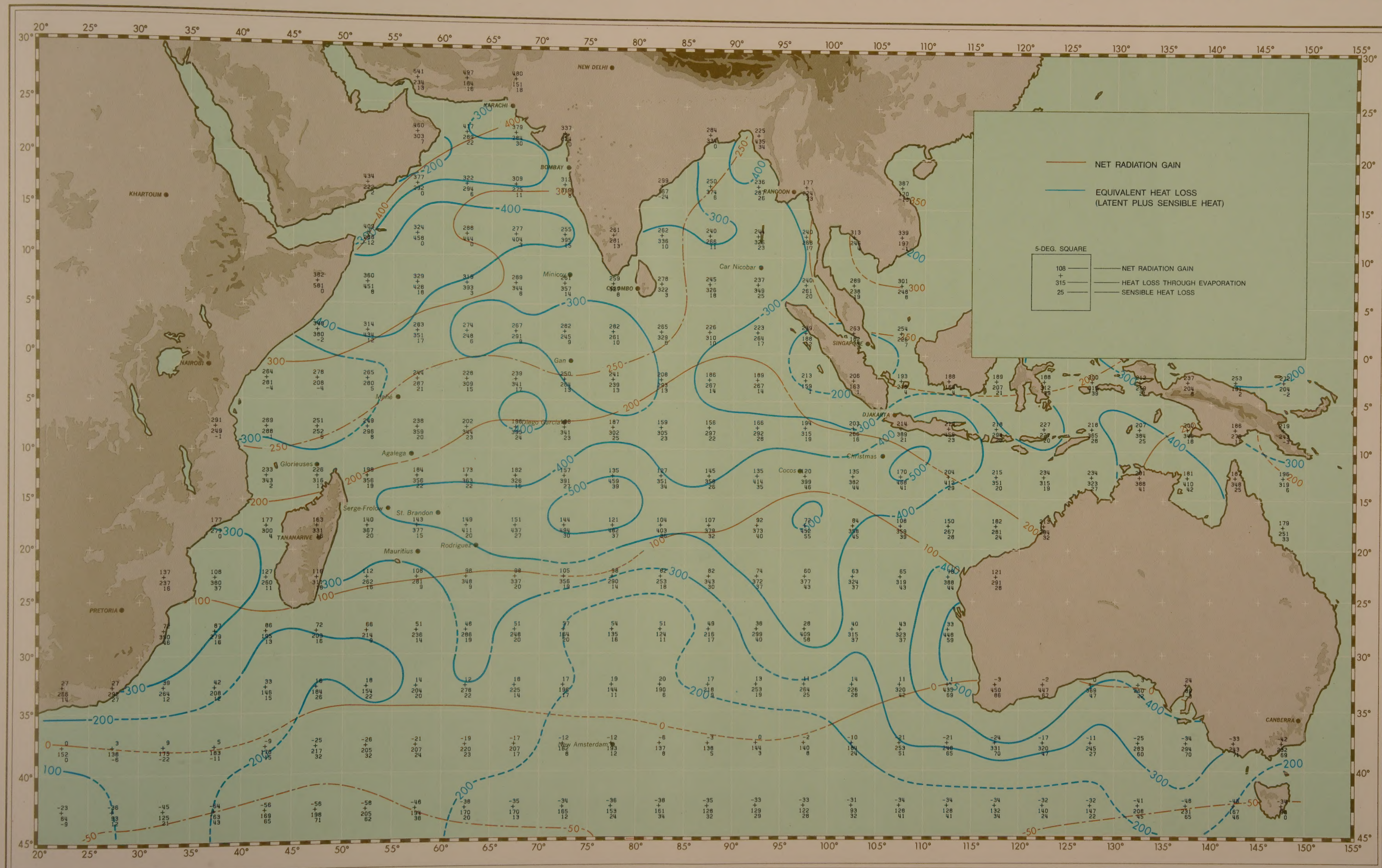


# HEAT EXCHANGE AT THE SEA SURFACE IN CAL CM<sup>-2</sup> DAY<sup>-1</sup> May 1964 Chart 137



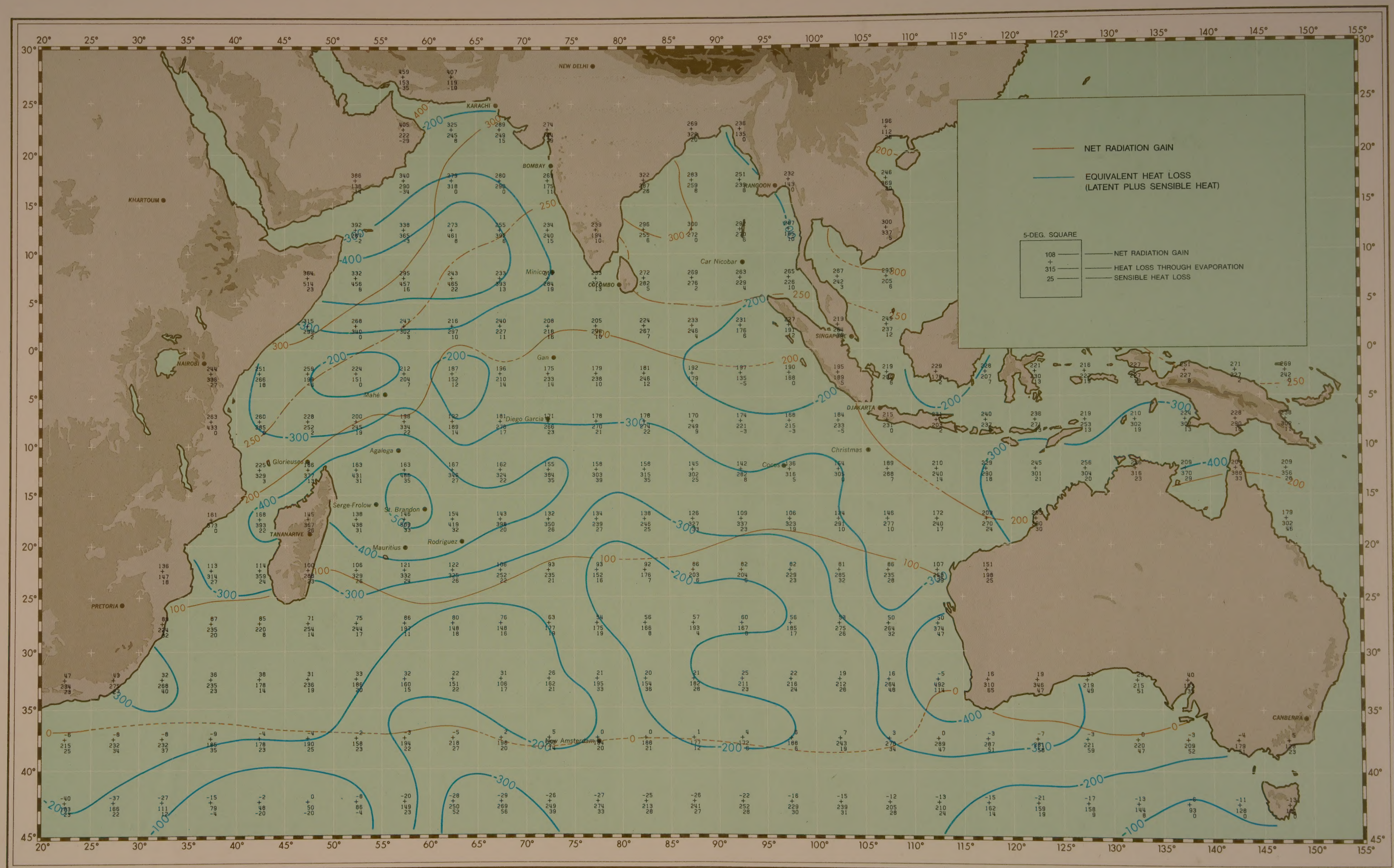


# HEAT EXCHANGE AT THE SEA SURFACE IN CAL CM<sup>-2</sup> DAY<sup>-1</sup> June 1964 Chart 138



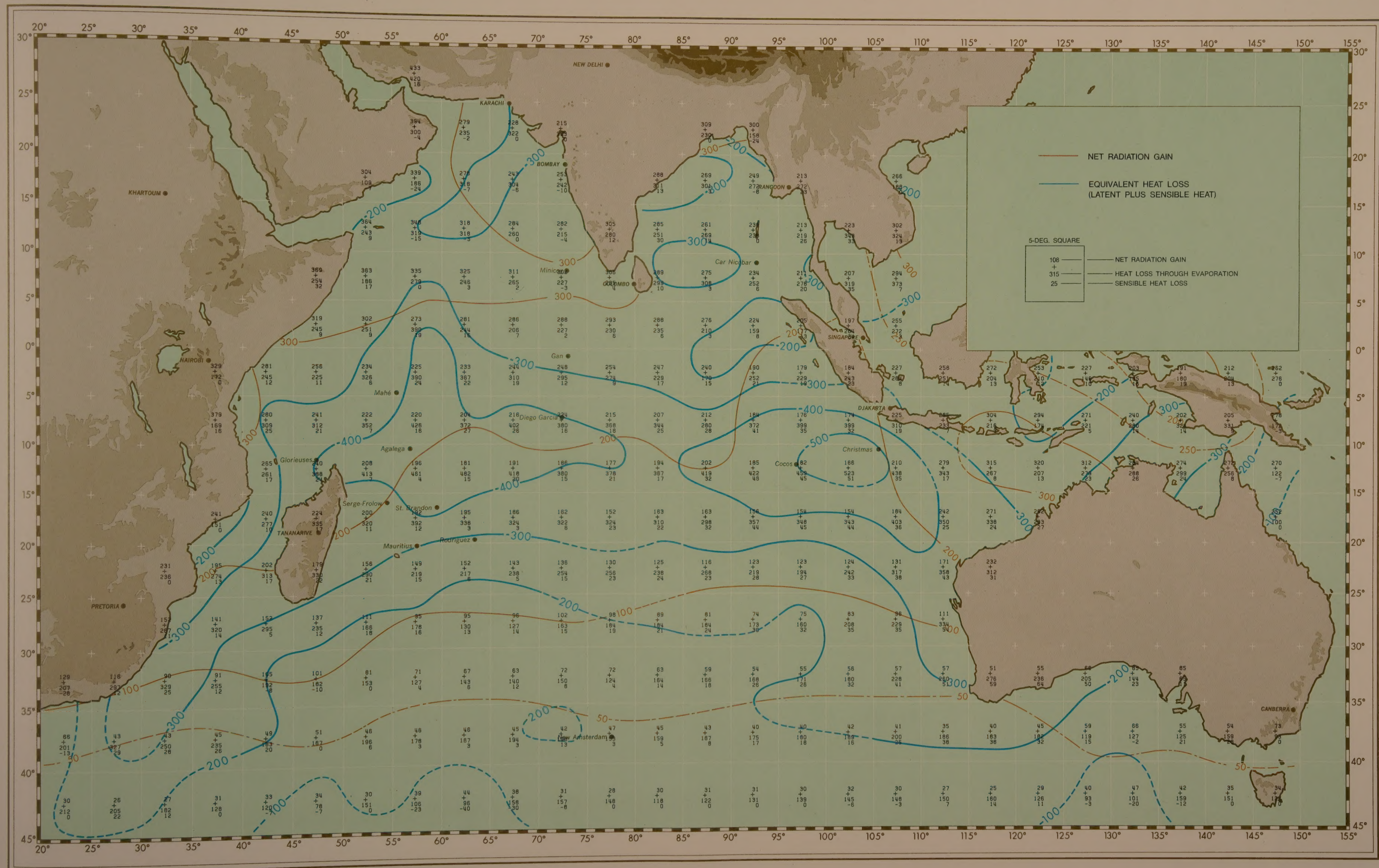


## Chart 139



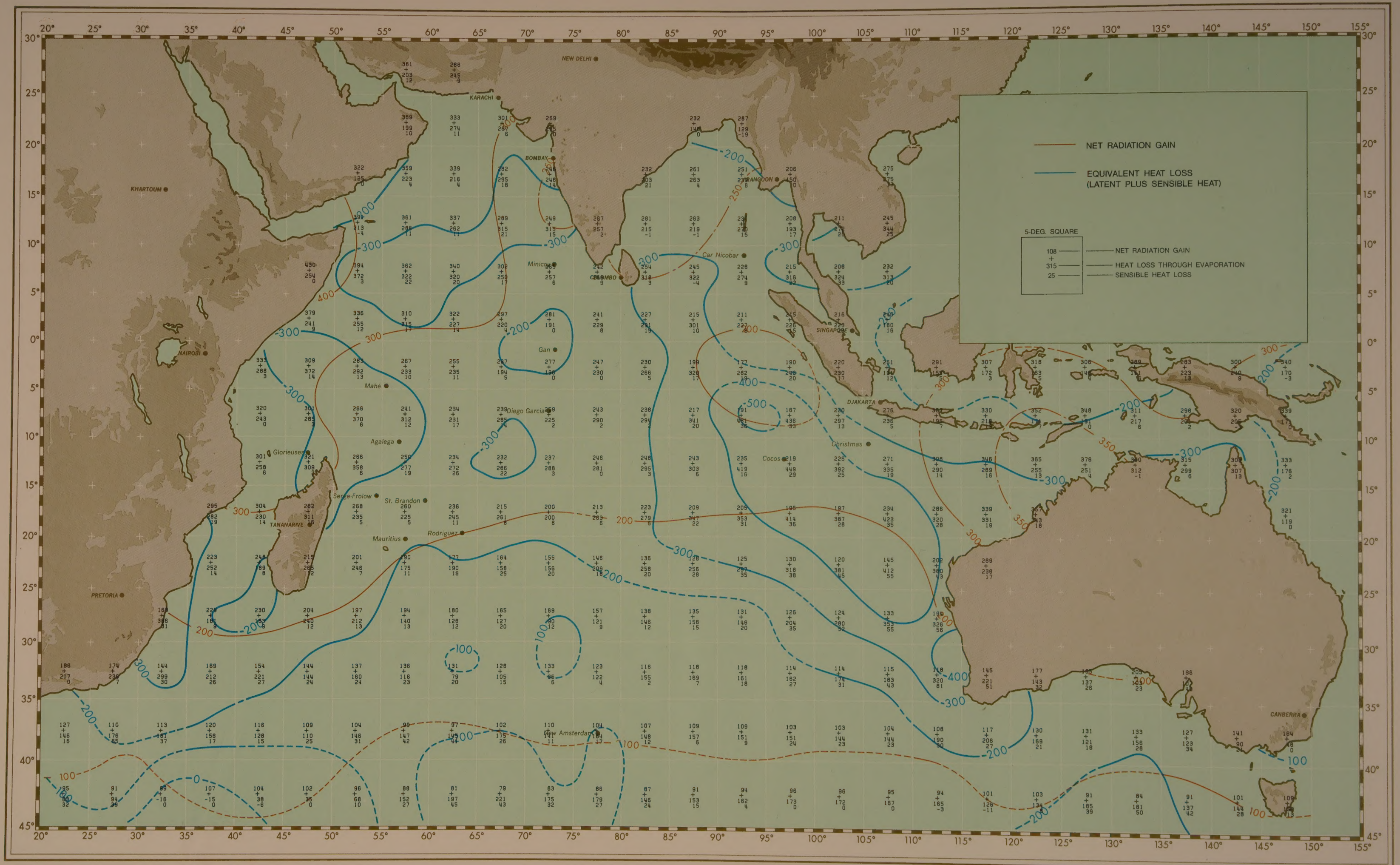


# HEAT EXCHANGE AT THE SEA SURFACE IN CAL CM<sup>-2</sup> DAY<sup>-1</sup> August 1964 Chart 140



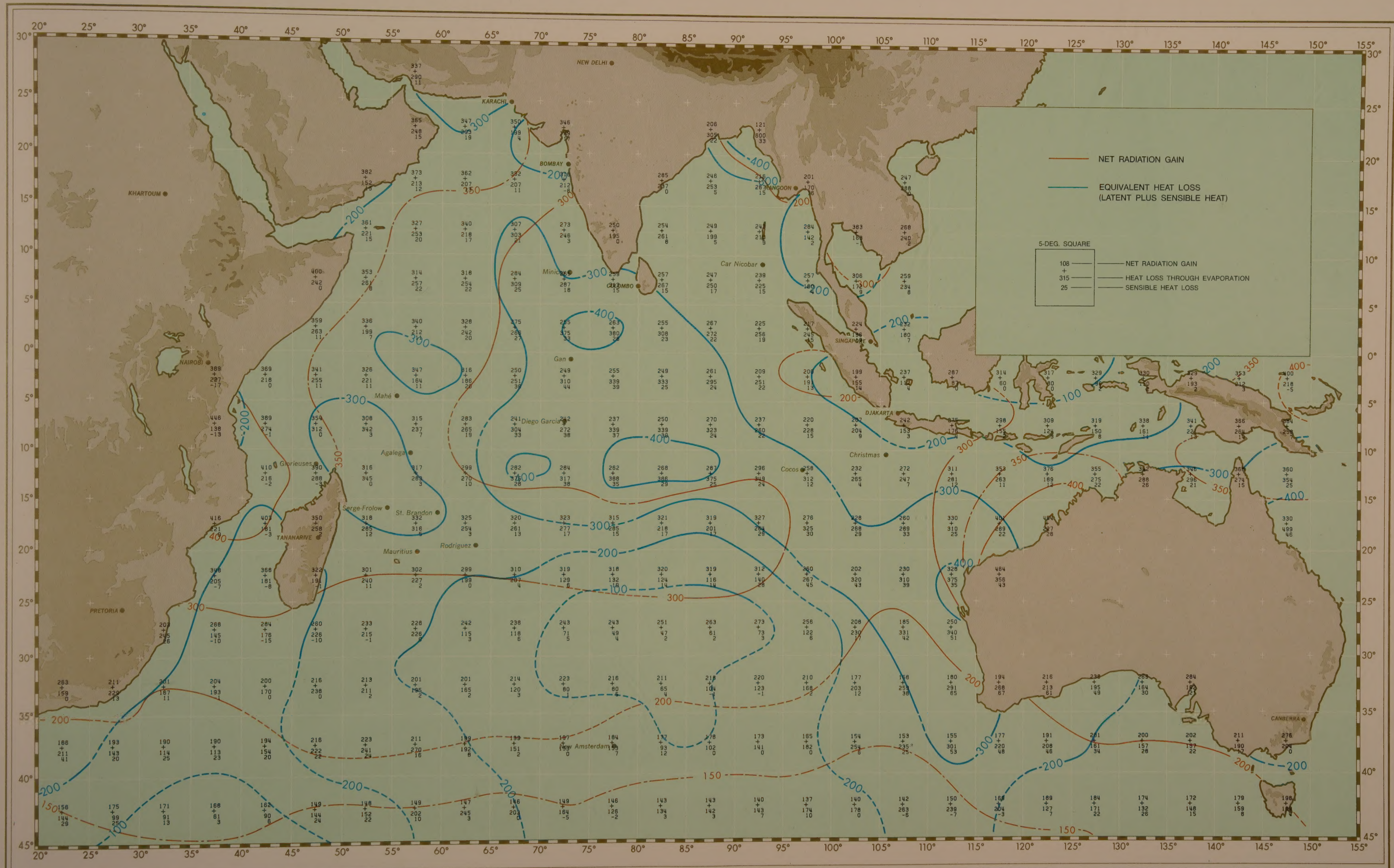


# HEAT EXCHANGE AT THE SEA SURFACE IN CAL CM<sup>-2</sup> DAY<sup>-1</sup> September 1964 Chart 141



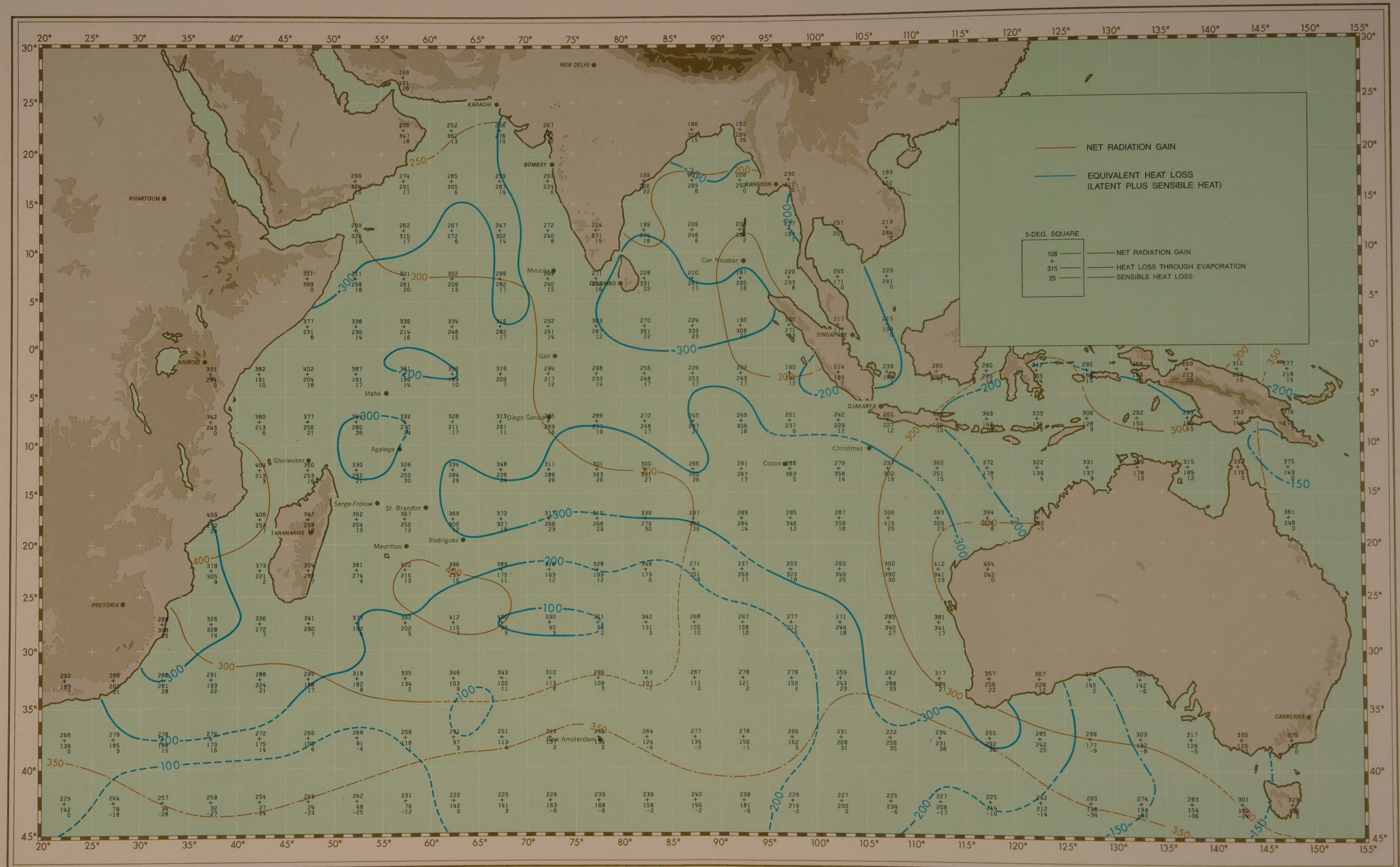


# HEAT EXCHANGE AT THE SEA SURFACE IN CAL CM<sup>-2</sup> DAY<sup>-1</sup> October 1964 Chart 142



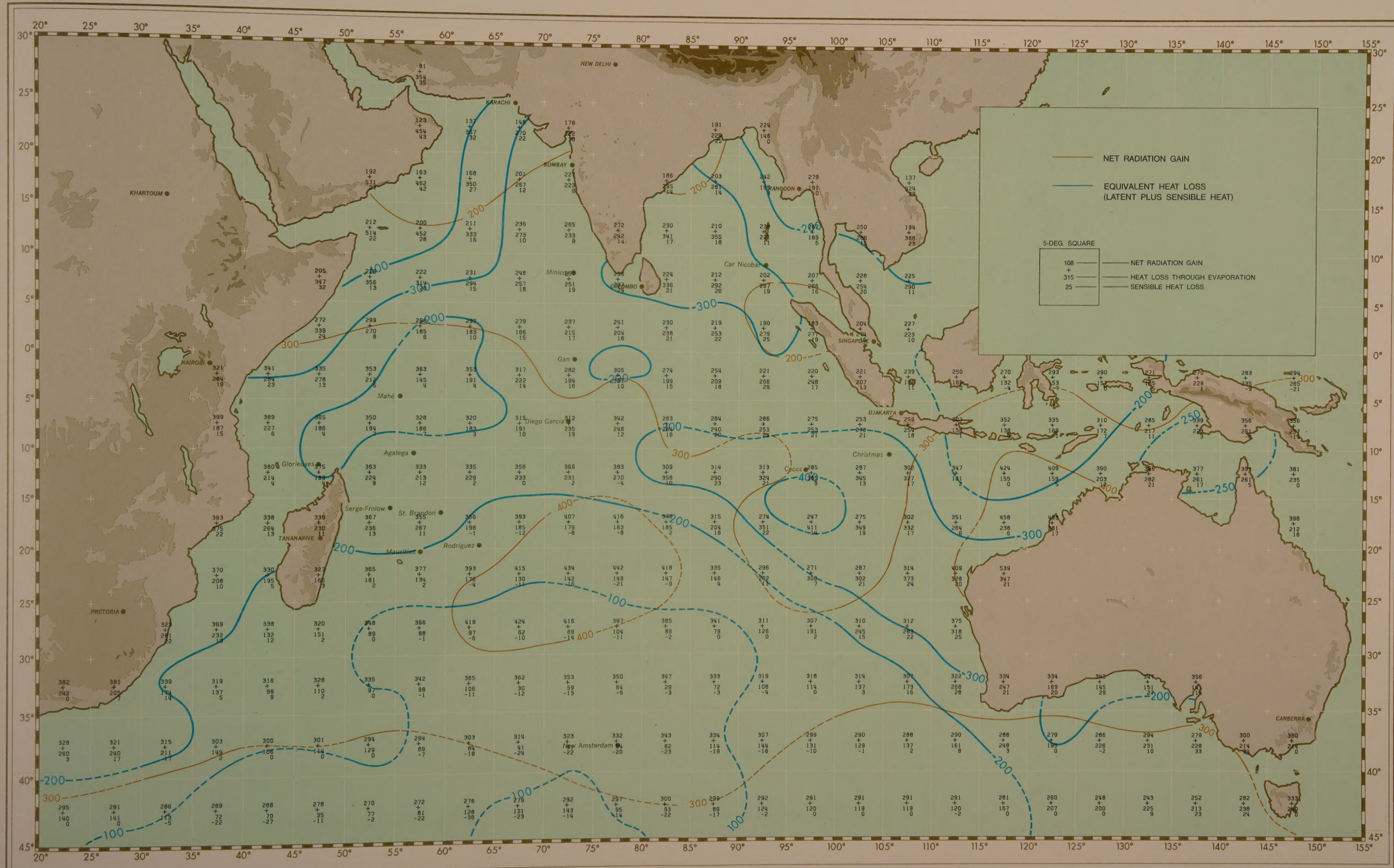


# HEAT EXCHANGE AT THE SEA SURFACE IN CAL CM<sup>-2</sup> DAY<sup>-1</sup> November 1964 Chart 143

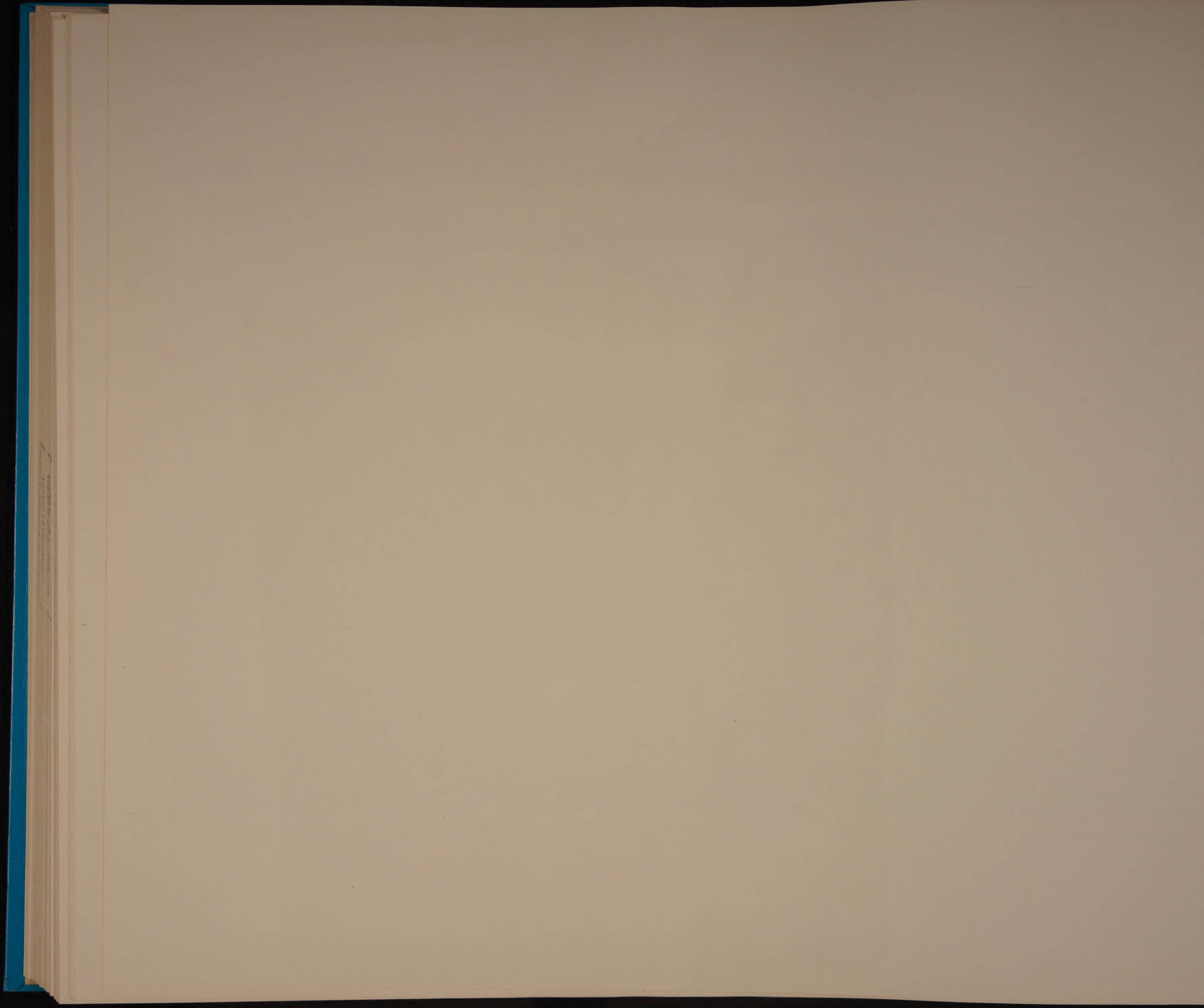




# HEAT EXCHANGE AT THE SEA SURFACE IN CAL CM<sup>-2</sup> DAY<sup>-1</sup> December 1964 Chart 144











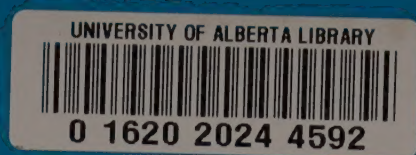




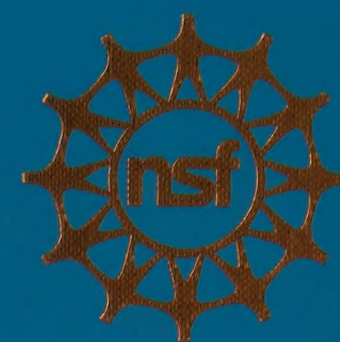
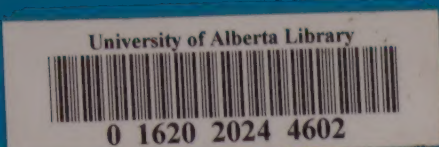












VOLUME 2

UPPER AIR

# METEOROLOGICAL ATLAS of the International Indian Ocean Expedition



NATIONAL SCIENCE FOUNDATION • WASHINGTON, D.C. • NOVEMBER, 1972





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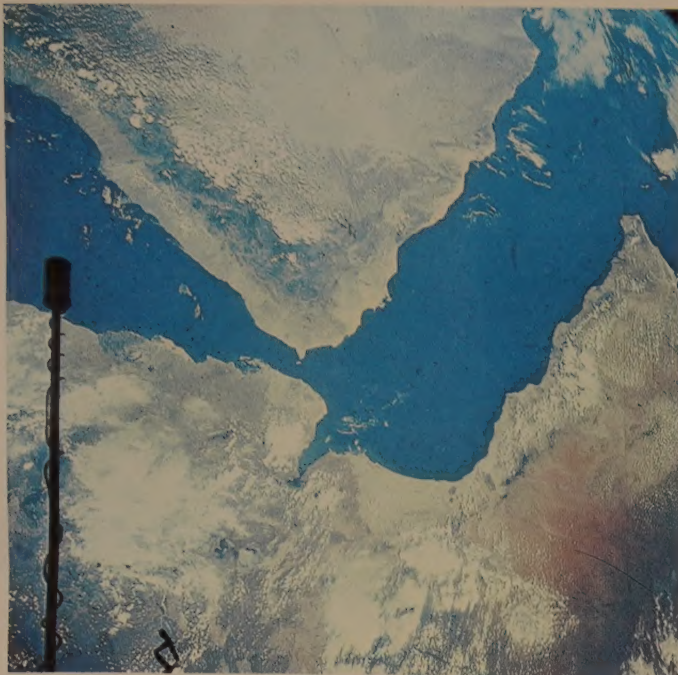












GEMINI XI SEPTEMBER 14, 1966

The Red Sea is at the left. From it the Gulf of Aden extends to the Indian Ocean on the horizon. Between the spacecraft and the V-shaped Tadjoura Gulf in the lower center of this photo is Lake Abbe. The boundary between Ethiopia and the Somali Republic crosses that lake. Yemen occupies the left part of the Arabian Peninsula shown here, and Aden is along the shore to the east. Major structural lineaments of the Arabian shield, and the dendritic wadi system of the Hadramawt Plateau, can be observed.



GEMINI XI SEPTEMBER 14, 1966

This panoramic oblique view from over the Indian Ocean embraces nearly the whole Arabian Sea. The horn of Africa and part of Dhufar, and Muscat and Oman are at the left. On the right the view extends past Pakistan, and well down the coast of India. The low-level wind was southwest in the foreground and northwest off India south of the Gulf of Cambay. The Gulf of Oman is near the upper left. South of it one can see the archlike structure of the Oman Range, and to the north the general trend of the Makran range in Iran is visible. The relationship between these mountains has long been an enigma.



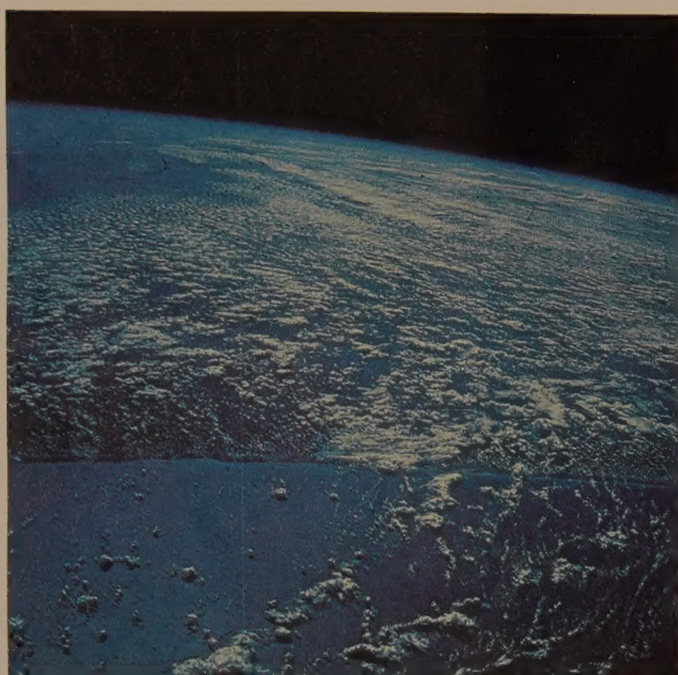
GEMINI XI SEPTEMBER 14, 1966

This picture includes all of Ceylon, yet the Himalayas, roughly 2300 miles away, are faintly visible on the horizon. Ceylon is 270 miles long. Its people are clustered on the moist southwestern third of the island. Dry areas elsewhere were irrigated and productive 2000 years ago, but later were neglected until recent times. At the upper right, cirrus clouds can be seen streaming westward toward Ceylon from a convective area in the Bay of Bengal. At top center there is another region of cloudiness near Calcutta. It is associated with a weak depression.



GEMINI XII NOVEMBER 14, 1966

This view northward over the Bay of Bengal shows the Irrawaddy River delta in Burma. The Gulf of Martaban in the lower right is 150 miles wide, and some of the river's several mouths are visible left of it. Rice is grown on the alluvial lowlands of this fertile delta. The brown, silt-laden water being discharged into the Andaman Sea is evidence of denudation upstream that has been estimated to be 1 foot in 400 years. At the left the northern part of the Andaman Islands can be seen. Cumulus streets prevail over the bay and sea, but there are also a few scattered cirrus clouds.



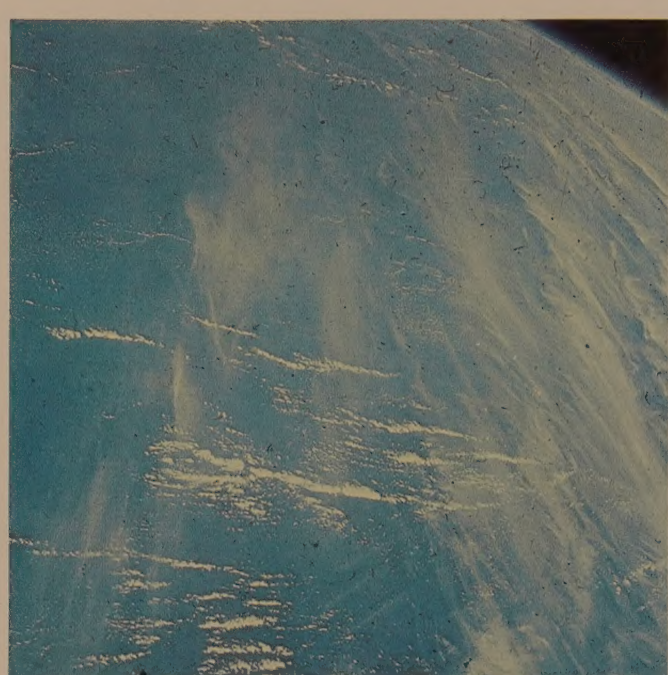
GEMINI IX JUNE 6, 1966

The coastal strip shown is part of the Somali Republic. The Equator crosses this area from the upper left to the lower right. Here the sea-surface temperature in the Somali Current is about 79° F in June, and you see fewer clouds over the water than over the land. The convective cloudiness covers the coastal lowlands and extends into northeastern Kenya, but over the highlands at the upper left—the region between the Indian Ocean and Lake Victoria—the sky is mostly quite clear.



GEMINI X JULY 21, 1966

Suvadiva is the large atoll here, Addu Atoll is below it, and the small island and reef of Fua Mulaku Island is between them. Within the lagoon of Suvadiva, the white spots are cumulus clouds, and the dark ones are coral knolls typical of Pacific and Indian Ocean atoll lagoons. The white, pearl-like fringe on the shores of both Suvadiva and Addu is the reflectance from strong surf produced as waves approach from the south. The prominent large white cumulonimbus in the foreground had reached the upper levels of the atmosphere, and the tops of these clouds were being blown to the southwest when this picture was taken.



GEMINI X JULY 21, 1966

This picture shows a thin veil of cirrus clouds being swept along by high-altitude east winds over the Indian Ocean south of Ceylon. The camera was pointed west, and the Maldives Islands are near the horizon, but too small and far away to be seen. Thunderstorms spew out long cirrus streamers which may extend for hundreds of miles in this tropical region. A different, lower level wind regime had aligned the cumulus clouds in the foreground in a north-south line at the time this picture was taken.



GEMINI XI SEPTEMBER 14, 1966

This view eastward across Sumatra shows the great quantities of cirrus produced by cumulonimbus clouds in this equatorial monsoon climate. The intense convective activity, which produces more than 100 inches of rain a year in much of this area, is particularly evident over northern Sumatra in the upper left, and along a line which cuts across the lower right corner of the picture. In the lower levels the undeveloped cumuli show open cellular patterns in some areas, as well as a suggestion of a vortex in the right center of the photo. Monthly mean temperatures average about 80° F at sea level in this part of Indonesia.



GEMINI VI DECEMBER 16, 1965

The Mayotte Archipelago is in the Mozambique Channel between Africa and the Malagasy Republic. This is a westward view of the Comoro Islands there. At the lower left is Mayotte, surrounded by an extensive, dangerous coral reef. In the center is Anjouan, which has a central peak 5170 feet high. Moheli, directly above it, is the smallest of these volcanic islands. Grande Comore is at the upper right, but covered by cumulus congestus clouds. The varied alignment of cumulus indicates a complex low-level wind pattern. A small cloud eddy induced by the light flow of air past the islands can be seen near the top of the picture.



GEMINI VI DECEMBER 16, 1965

This is an eastward look at the southern edge of a tropical vortex seen over the waters of the southern Indian Ocean. The alignment at different altitudes shows the changes in the wind direction with height. Of particular interest here is the apparent alignment of the lower clouds. This suggests that there was a diverging northeasterly flow, but because such a flow is not likely so near to storms, the apparent alignment may have resulted from the perspective of the photograph.



GEMINI IX JUNE 6, 1966

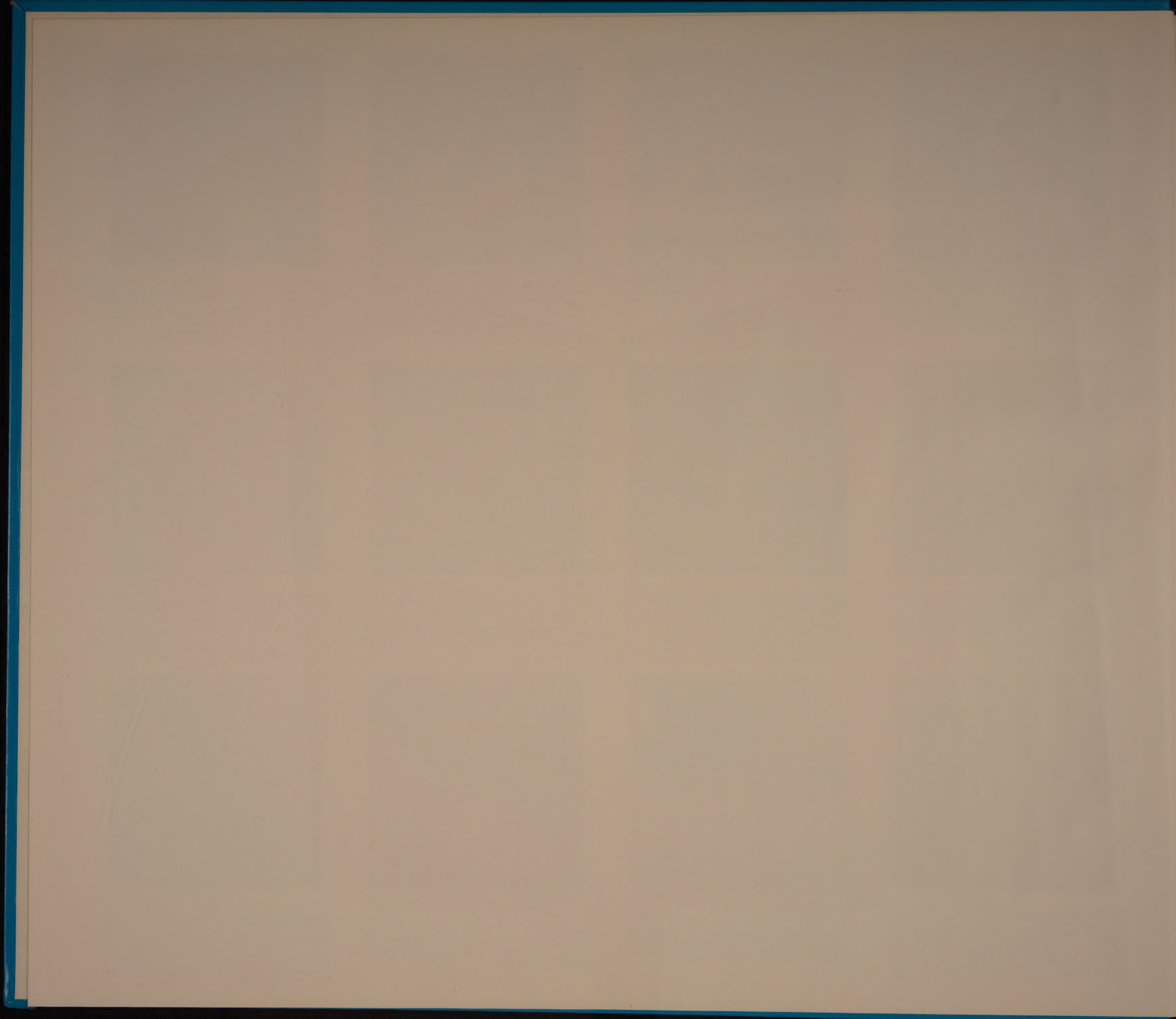
These stratocumulus clouds seen over the southeastern Indian Ocean looked like floating fields of ice, but the orbits of the Gemini flights kept them well away from the polar regions of the Earth. Similar cloud forms frequently are seen off the coasts of California and Peru where the waters of the Pacific are relatively cool. Some cellular patterns are discernible in this stratocumulus, indicating that a Bénard cell-type circulation might be found in the lower atmosphere. A few cirrus clouds also are scattered throughout the photo.



GEMINI XI SEPTEMBER 14, 1966

This is a wide-angle photo of Australia's northwestern coast with Eighty Mile Beach in the foreground. Inland is the Great Sandy Desert; the Lake Mackay is near the center of the right edge. In the upper left, parts of Timor are visible despite dense clouds such as persist over Indonesia much of the year. The Gulf of Carpentaria is near the horizon on the right. Cumulus-cloud patterns cover hilly regions below it. A vast Precambrian shield extends across Australia from Perth to the Gulf of Carpentaria. The area is a broad complex of pillow lavas, tuffs, and greenstones, flanked by metasediments, all of which are intruded by granites.









VOLUME 2

**METEOROLOGICAL**  
**ATLAS of the**  
**International**  
**Indian Ocean**  
**Expedition**

UPPER AIR

by

C. S. RAMAGE

and

C. V. R. RAMAN

A Joint Project  
of the

U.S. National  
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and

India Meteorological  
Department



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## Preface

The International Indian Ocean Expedition which lasted from 1959 to 1965 was a multinational, multidisciplinary attempt to study and possibly explain the physical and biological characteristics of the "monsoon" ocean. Meteorologists were active during the Expedition, collecting countless observations from ships, land stations, aircraft, and satellites.

Under the auspices of the Intergovernmental Oceanographic Commission of UNESCO, a series of Expedition Atlases is being published, including a two-volume Meteorological Atlas.

Volume 2 describes the upper-air climate of the Indian Ocean and its neighboring continents, and incorporates information obtained from before, during, and after the Expedition period. Monthly long-term averages of resultant wind, wind steadiness, pressure height, temperature, and dew point are presented on two sets of charts—(1) constant pressure-level charts for 850, 700, 500, 300, 200, and 100 mb (approximately 1.5, 3.1, 5.8, 9.6, 12.4, and 16.5 km above m.s.l., respectively) covering the area between 45N and 50S and 20E and 155E, and (2) 45N to 50S meridional cross-section charts for longitudes 30E, 73E, 100E, and 140E. Analysis on the constant pressure-level charts consists of streamlines and isotachs; shown on the meridional charts are isotachs of the zonal wind component and isentropes.

Besides averages computed from sounding-balloon observations, flying-level winds measured from aircraft provided significant detail over the open ocean.

Meteorologists, climatologists, and airline operators should be among those finding this volume useful. From the plotted data they will be able to construct different sets of isopleths.

Projection (Mercator's) and scale (1:40 million) conform to World Meteorological Organization specifications for meteorological atlases.

Contribution No. 72-2 of the Department of Meteorology, University of Hawaii.







## Acknowledgements

We are happy to acknowledge the many individuals and organizations contributing to this volume. Incorporated in the averages are the results of approximately 750,000 balloon ascents made at 274 stations operated by 45 meteorological services; 118,000 wind measurements made by crews of 32 airlines and air forces and several hundred soundings made from IIOE research vessels and from naval vessels. Averages of most of the fixed-station soundings were contained in magnetic tapes and microfilms supplied by the U.S. National Weather Records Center, Asheville, North Carolina.

Officials of three organizations continuously helped and encouraged us: Drs. E. G. Droessler, and F. D. White successively Head of the Atmospheric Sciences Section of the U.S. National Science Foundation; Mr. P. R. Krishna Rao, Mr. C. Ramaswamy, and Dr. L. S. Mathur successively Director-General of the India Meteorological Department; and Dr. W. S. Wooster and Dr. K. N. Fedorov successively Director of the Office of Oceanography, UNESCO. The World Meteorological Organization, directly and through its administration of UN Special Fund support, contributed in many ways; the counsel of Dr. K. R. Ramanathan was invaluable.

In our preliminary work, undertaken at the International Meteorological Center, Bombay, we owe much to Mr. C. M. Dixit and other IMC staff members. Most of the ideas incorporated in this volume were developed in discussions with them.

At the University of Hawaii, Mr. J. R. Nicholson, Mr. F. R. Miller, Mrs. C. Jefferies, and Mr. F. P. Ho and scientists at the University Computing Center gave valuable professional advice, while the work of Mrs. M. Hamao (typing), Mrs. E. U. McAfee (editing), Mr. R. R. Rhodes and Mr. L. K. Oda (drafting), and Mrs. J. Heavenridge (production planning) was of the highest quality.

Mr. H. W. Holmerud of Stromberg Datagraphics, Inc. investigated the feasibility of using a cathode ray-tube process for data printing; with advice and programming help from Mr. A. F. Brady of California Computer Products, Inc., we were able to arrange for the data to be plotted on a Calcomp 718 machine at Camp H. M. Smith, Honolulu.

The Atmospheric Sciences Section of the National Science Foundation supported preparation of the Atlas under NSF Grant GA-386 and Mr. J. C. Holmes of the Foundation was in charge of publication.







# Introduction

The International Indian Ocean Expedition (IIOE) embodied an unprecedentedly massive effort to explore, describe, and understand the physical, chemical, and biological interactions in a sizable fraction of the water-atmosphere realm of the world (UNESCO, 1965- ). Although surveys were begun in 1957 and research vessels were still probing at the end of 1965, activity was concentrated in 1963 and 1964. The meteorologists, working from their Bombay base at the International Meteorological Center (IMC)\* selected 1963 and 1964 for a series of special studies of air-sea interactions and synoptic scale features, using buoys, radiometric recordings, and long-range research aircraft (Ramage, 1965). Investigators need to view results from the oceanographic cruises and the special meteorological studies in an overall meteorological framework before attempting to generalize their conclusions, and an atlas can best provide that framework. Thus, at its Fourth Session (from 3 to 12 November 1965), the Intergovernmental Oceanographic Commission appointed the senior author as editor, with the task of preparing a two-volume International Indian Ocean Expedition Meteorological Atlas. Representatives of India, the United Kingdom, and the USSR were to constitute an Editorial Advisory Board. In August 1966 the United Kingdom appointed Mr. J. G. Cottis to the Board.

Volume 1 describes the surface climate of the Indian Ocean during 1963 and 1964; Volume 2 describes the upper-air climatology, using all available data through 1966.

Two atlases which include upper-air charts of the Indian Ocean have been published. The first atlas (Ramanathan and Venkiteswaran, 1948) depended entirely on pilot-balloon observations and therefore largely reflects fair weather circulation features. The second (U.S. Weather Bureau, 1957), which does incorporate some averages based on rawinsonde ascents, divides the year into seasons; it is particularly skimpy over the open ocean. Since long-term upper-air averages have never been established and we were not able to determine departures from normal of the IIOE years, we decided to incorporate all readily available upper-air data in Volume 2.

Volume 2 expands on preliminary analyses—given limited distribution (Raman and Dixit, 1964)—as well as on the analyses published by the Meteorological Department, Thailand (1965), and by Frost and Stephenson (1965). Observations from the ocean stations of Minicoy, Diego Garcia, and Mahé, established for IIOE, and from commercial aircraft as well as research vessels and aircraft have for the first time enabled us to delineate mean circulation patterns over the open ocean with some confidence.

Ramage (1972) discusses major circulation features depicted in the charts.

\* Established and operated by the India Meteorological Department with help from the United Nations (WMO) Special Fund and the U.S. National Science Foundation.

## GENERAL PLAN FOR CHARTS

The series "Marine Climatic Atlas of the World," published by the U.S. Navy, comprises seven volumes covering every ocean (Volume III (1957) describes the Indian Ocean). To facilitate comparison, we have used the same projection (Mercator's) and scale (1:40 million) for the surface and constant pressure-level charts as were used in the Navy Atlas. This projection and scale conform to specifications for marine climatic atlases as laid down by the World Meteorological Organization (1960).

In Volume 2, monthly averages of resultant wind, wind steadiness, pressure height, temperature, and dew point are presented on two sets of charts.

## CONSTANT PRESSURE-LEVEL CHARTS

The Indian Ocean is delimited by the southern coasts of Asia and Indonesia, the eastern coast of Africa and longitude 20E, and the western and southern coasts of Australia and longitude 145E. Observations made at or over the surface of the ocean can be similarly and logically delimited. However, above the surface these boundaries are artificial and unrealistic and so we have extended the data processing and analysis to encompass the whole rectangle enclosing the Indian Ocean. The base charts for 850, 700, 500, 300, 200, and 100 mb (approximately 1.5, 3.1, 5.8, 9.6, 12.4, and 16.5 km above m.s.l., respectively) show locations of fixed upper-air sounding stations and land contours at 1000, 3000, and 5000 m intervals.

## CROSS SECTION CHARTS

Along four meridians (30E, 73E, 100E, 140E), data are adequate for the construction of atmospheric cross sections. One month is represented on two facing pages; projection (Mercator's) and scale (1:40 million) of the abscissa (latitude) are the same as for the constant pressure-level charts; the ordinate (log p) extends to 100 mb, above which data are scanty. The charts show general terrain levels and major peaks within 50 km of the section line.

## DATA SOURCES

### FIXED STATIONS (SEE CHART 1)

The U.S. National Weather Records Center in Asheville, North Carolina, supplied microfilmed copies of long-term rawinsonde averages for 150



stations. Data for the remaining stations were compiled from the Monthly Climatic Data of the World and published records of Meteorological Services. Periods of record varied, but the station averages were considered to be stabilized if they were derived from at least five years of data.

Records of less than five years were increased by utilizing recent publications and the averages computed for the IIOE years of 1963 and 1964. Stations established during IIOE, such as Minicoy, Diego Garcia, and Mahé still fall somewhat short of a desirable record length.

#### MOVING STATIONS (SEE TABLES 1 AND 2)

Thompson (1951) was one of the first to demonstrate that aircraft flying-level winds could contribute to climatology. The advent of doppler navigation systems has led to improved wind measurements, while the electronic computer has greatly speeded calculation of averages. Thanks to the excellent cooperation of airlines and meteorological services, 118,000 aircraft wind reports have been assembled.

We have also collected 450 reports of pilot balloon or radar wind-soundings, and 1650 radio soundings made from ships, chiefly research and naval vessels. Finally, drop soundings from research aircraft totaled 220.

#### DATA PROCESSING

##### DATA FROM FIXED STATIONS

The long-term averages from the Asheville file were transferred to punch cards. For stations with insufficient lengths of record, or with records ending prior to 1960, additional years of data were obtained and merged with the Asheville averages. This expanded file was then transferred to magnetic tape.

Summaries based on varied observation hours and varied periods of record differed negligibly for levels above 850 mb.

##### DATA FROM MOVING STATIONS

For each month standard pressure level observations from ships and aircraft were punched on cards, sorted into 5-degree squares, and averaged.

#### PLOTTING AND ANALYSIS

##### CONSTANT PRESSURE-LEVEL CHARTS

The data tapes were fed into a Benson-Lehner curve plotter, programmed to print out monthly averages of pressure height, temperature, dew point, resultant wind, and steadiness at each fixed-station location and at the average position of the moving stations in each 5-degree square. The plotter also drew a vector corresponding to each mean resultant wind.

We then made a kinematic analysis of the charts (streamlines and isotachs). A preliminary set of analyses made at IMC, Bombay, in 1963, served as a "first guess" and greatly facilitated the work. Moving station averages plotted for the 250 mb level aided analyses both at 300 and at 200 mb.

The final analyses were generally simpler than the preliminary analyses, suggesting that the data were sufficient to define the mean flow patterns unequivocally.

##### LONGITUDINAL CROSS SECTIONS

Again, the data tapes were fed into the Benson-Lehner curve plotter which was programmed this time to print, at standard pressure levels (including 400 and 250 mb) on each cross-section chart, monthly averages from fixed stations within 2.5 degrees of the cross-section longitude. The plotter entered averages of north-south (meridional) and east-west (zonal) components of the wind, pressure height, dew point, and potential temperature. Wind velocities, read from the analyzed constant pressure-level charts at 5-degree intervals along each cross-section meridian, were punched on

TABLE 1. DISTRIBUTION OF AIRCRAFT REPORTS

| Pressure Level (mb) | Jan     | Feb   | Mar   | Apr    | May   | Jun   | Jul    | Aug    | Sep    | Oct   | Nov   | Dec   |
|---------------------|---------|-------|-------|--------|-------|-------|--------|--------|--------|-------|-------|-------|
| 850                 | 29      | 150   | 117   | 30     | 65    | 48    | 59     | 68     | 52     | 58    | 51    | 52    |
| 700                 | 438     | 827   | 775   | 745    | 763   | 740   | 775    | 501    | 546    | 526   | 374   | 614   |
| 600                 | 442     | 504   | 439   | 573    | 314   | 286   | 284    | 279    | 348    | 371   | 385   | 473   |
| 500                 | 916     | 1,112 | 1,077 | 1,319  | 1,055 | 1,099 | 1,094  | 1,008  | 1,079  | 891   | 905   | 975   |
| 400                 | 122     | 154   | 121   | 115    | 135   | 153   | 148    | 168    | 162    | 132   | 44    | 91    |
| 300                 | 2,343   | 1,740 | 2,138 | 1,830  | 1,671 | 1,904 | 1,980  | 1,828  | 2,088  | 1,780 | 2,041 | 2,077 |
| 250                 | 4,162   | 3,770 | 4,117 | 4,076  | 3,829 | 4,481 | 4,616  | 5,064  | 5,285  | 4,982 | 4,737 | 4,528 |
| 200                 | 1,080   | 1,024 | 1,211 | 1,341  | 1,231 | 1,136 | 1,161  | 1,185  | 1,066  | 1,282 | 1,163 | 991   |
| Total               | 9,532   | 9,281 | 9,995 | 10,029 | 9,063 | 9,847 | 10,117 | 10,101 | 10,626 | 9,922 | 9,700 | 9,801 |
| Grand Total         | 118,022 |       |       |        |       |       |        |        |        |       |       |       |



TABLE 2.  
SOURCES OF AIRCRAFT REPORTS

| Route                           | Flight levels (mb) |     |     |     |     |     |     | Airlines   |           |          |            |      |     |                |                 |              |           |        |               |     |     |           |           |             |           |              |            |     |        |                 |        |     |               |           |     |      |     |             |     |   |
|---------------------------------|--------------------|-----|-----|-----|-----|-----|-----|------------|-----------|----------|------------|------|-----|----------------|-----------------|--------------|-----------|--------|---------------|-----|-----|-----------|-----------|-------------|-----------|--------------|------------|-----|--------|-----------------|--------|-----|---------------|-----------|-----|------|-----|-------------|-----|---|
|                                 | 850                | 700 | 500 | 400 | 300 | 250 | 200 | Air France | Air India | Alitalia | Ansett-ANA | BOAC | CAT | Cathay Pacific | Central African | East African | Ethiopian | Indian | Iran National | JAL | KLM | Lufthansa | Malaysian | Middle East | Northwest | Pan American | Philippine | PIA | QANTAS | Royal Air Force | Sabena | SAS | South African | Swiss Air | TAA | Thai | TWA | United Arab | UTA |   |
| Adelaide-Melbourne              |                    |     |     |     | •   | •   | •   |            |           |          | •          |      |     |                |                 |              |           |        |               |     |     |           |           |             |           |              |            |     |        |                 |        |     |               |           |     | •    |     |             |     |   |
| Aden-Bombay                     |                    | •   | •   | •   | •   | •   | •   |            | •         |          |            |      |     |                |                 |              |           |        |               |     |     |           |           |             |           |              |            |     |        |                 |        |     |               |           |     |      |     |             |     |   |
| Aden-Cairo                      | •                  | •   | •   | •   | •   | •   | •   |            |           |          |            | •    |     |                |                 |              | •         |        |               |     |     |           |           |             |           |              |            |     |        |                 |        |     |               |           |     |      |     |             | •   |   |
| Aden-Gan                        |                    | •   | •   | •   | •   | •   | •   |            |           |          |            |      |     |                |                 |              |           |        |               |     |     |           |           |             |           |              |            |     |        |                 | •      |     |               |           |     |      |     |             | •   |   |
| Aden-Karachi                    |                    | •   | •   |     |     |     | •   |            | •         |          |            |      |     |                |                 | •            |           |        |               |     |     |           |           |             |           |              |            |     |        |                 |        | •   |               |           |     |      |     |             |     |   |
| Aden-Khartoum                   | •                  | •   | •   | •   | •   | •   |     |            |           | •        |            |      | •   |                |                 |              | •         |        |               |     |     |           |           |             |           |              |            |     |        |                 |        |     |               |           |     |      |     |             | •   |   |
| Aden-Nairobi                    |                    | •   | •   | •   | •   | •   | •   |            | •         |          |            |      |     |                |                 |              |           |        |               |     |     |           |           |             |           |              |            |     |        |                 |        |     |               |           |     |      |     |             | •   |   |
| Athens-Cairo                    |                    | •   |     |     | •   | •   | •   |            | •         |          |            |      |     |                |                 |              | •         |        |               |     |     | •         |           |             |           |              |            |     |        |                 |        | •   |               | •         |     |      |     |             | •   |   |
| Bangkok-Bombay                  |                    | •   | •   | •   | •   | •   | •   |            | •         |          | •          |      | •   |                |                 |              |           |        |               |     | •   |           |           |             |           |              |            |     |        |                 | •      |     | •             |           |     |      |     |             | •   |   |
| Bangkok-Calcutta                |                    | •   | •   | •   | •   | •   | •   |            | •         |          | •          |      |     |                | •               |              |           |        |               |     | •   | •         | •         |             |           |              |            | •   |        |                 |        |     | •             |           |     |      |     |             |     |   |
| Bangkok-Hong Kong-Tokyo         |                    | •   | •   | •   | •   | •   | •   |            | •         |          | •          |      |     |                |                 |              |           |        |               |     | •   | •         | •         | •           |           |              |            | •   |        |                 |        |     | •             |           |     |      |     |             |     |   |
| Bangkok-Karachi                 |                    | •   | •   | •   | •   | •   | •   |            | •         |          | •          |      |     |                |                 |              |           |        |               |     | •   | •         | •         |             |           |              |            | •   |        |                 |        |     | •             |           |     |      |     |             | •   |   |
| Bangkok-Manila                  |                    | •   | •   | •   | •   | •   | •   |            | •         |          | •          |      |     |                | •               |              |           |        |               |     | •   | •         | •         |             |           |              |            | •   |        |                 |        |     | •             |           |     |      |     |             |     |   |
| Bangkok-Singapore               |                    | •   | •   | •   | •   | •   | •   |            | •         |          | •          |      |     |                |                 |              |           |        |               |     | •   | •         | •         | •           |           |              |            | •   |        |                 |        |     | •             |           |     |      |     |             |     |   |
| Bombay-Cairo/Beirut             |                    | •   | •   | •   | •   | •   | •   |            | •         | •        | •          |      |     |                |                 |              |           |        |               |     | •   | •         | •         | •           |           |              |            | •   |        |                 |        |     |               |           |     |      |     |             | •   |   |
| Bombay-Calcutta                 |                    |     | •   | •   | •   | •   | •   |            |           | •        |            |      |     |                |                 |              |           | •      |               |     | •   | •         | •         | •           |           |              |            |     |        |                 |        |     |               | •         |     |      |     |             |     |   |
| Bombay-Colombo-Singapore        |                    | •   | •   | •   | •   | •   | •   |            |           |          |            |      |     |                |                 |              |           |        |               |     | •   | •         | •         |             |           |              |            |     |        |                 | •      |     |               |           |     |      |     |             |     |   |
| Bombay-Karachi-Tehran-Istanbul  |                    | •   | •   | •   | •   | •   | •   |            | •         | •        | •          |      |     |                |                 |              |           |        |               | •   | •   | •         |           |             |           |              | •          |     | •      |                 |        | •   | •             |           |     |      |     |             |     |   |
| Cairo-Khartoum-Entebbe-Nairobi  | •                  | •   | •   | •   | •   | •   | •   |            | •         | •        | •          |      |     |                |                 |              |           |        |               |     |     | •         |           |             |           |              |            |     |        |                 |        |     |               |           |     |      |     |             | •   |   |
| Cairo-Rome                      |                    |     | •   | •   | •   | •   | •   |            | •         |          | •          |      |     |                |                 |              |           |        |               |     | •   | •         | •         |             |           |              |            |     |        |                 | •      |     |               |           |     |      |     |             |     |   |
| Calcutta-New Delhi-Teheran      |                    | •   | •   | •   | •   | •   | •   |            | •         |          |            |      |     |                |                 |              |           | •      |               |     | •   | •         | •         |             |           |              |            | •   |        |                 |        | •   |               |           |     |      |     |             |     |   |
| Calcutta-Rangoon-Singapore      |                    | •   | •   | •   | •   | •   | •   |            |           |          |            |      |     | •              |                 |              |           | •      |               |     | •   | •         |           |             |           |              |            | •   |        |                 |        |     |               |           |     | •    |     |             |     |   |
| Cocos-Gan                       |                    | •   | •   | •   | •   | •   | •   |            |           |          |            |      |     |                |                 |              |           |        |               |     |     |           |           |             |           |              |            |     |        |                 |        | •   |               |           |     |      |     |             |     |   |
| Darwin-Singapore                |                    | •   | •   | •   | •   | •   | •   |            |           |          |            |      |     |                |                 |              |           |        |               |     |     |           |           |             |           |              |            |     |        |                 |        |     |               |           |     |      |     |             |     |   |
| Darwin-Sydney                   |                    | •   | •   | •   | •   | •   | •   |            |           |          |            |      |     |                |                 |              |           |        |               |     | •   | •         |           |             |           |              |            |     |        |                 |        |     |               |           |     | •    |     |             |     |   |
| Djibuti-Entebbe                 |                    | •   | •   | •   | •   | •   | •   |            |           |          |            |      |     |                |                 |              | •         |        |               |     |     |           |           |             |           |              |            |     |        |                 |        |     |               |           |     |      | •   |             |     |   |
| Gan-Singapore                   |                    | •   | •   | •   | •   | •   | •   |            |           |          |            |      |     |                |                 |              |           |        |               |     |     |           |           |             |           |              |            |     |        |                 |        | •   |               |           |     |      |     |             |     |   |
| Hong Kong-Singapore             |                    | •   | •   | •   | •   | •   | •   |            |           |          |            |      |     |                |                 |              |           |        |               | •   |     |           | •         |             |           |              | •          |     |        |                 |        |     |               |           |     |      | •   |             |     |   |
| Honolulu-Guam-Manila            |                    | •   | •   | •   | •   | •   | •   |            |           |          |            |      |     |                |                 |              |           |        |               |     |     |           |           |             |           |              | •          | •   |        |                 |        |     |               |           |     |      |     |             |     |   |
| Johannesburg-Lagos              |                    | •   | •   | •   | •   | •   | •   |            |           |          |            |      |     |                |                 |              |           |        |               |     |     | •         |           |             |           |              |            |     |        |                 |        |     |               |           |     |      |     |             |     |   |
| Johannesburg-Nairobi            |                    | •   | •   | •   | •   | •   | •   |            |           | •        |            |      |     |                | •               |              |           |        |               |     |     |           |           |             |           |              |            |     |        |                 |        |     |               |           |     |      |     |             |     |   |
| Johannesburg-Perth              |                    | •   | •   | •   |     |     |     | •          |           |          |            |      |     |                |                 |              |           |        |               |     |     |           |           |             |           |              |            |     |        |                 | •      |     |               |           | •   |      |     |             |     |   |
| Karachi-Multan                  |                    | •   | •   | •   | •   | •   | •   |            |           |          |            |      |     |                |                 |              |           |        |               |     |     |           |           |             |           |              |            |     | •      |                 |        |     |               |           |     |      |     |             |     |   |
| Karachi-Nairobi                 |                    | •   | •   | •   | •   | •   | •   |            |           |          |            | •    |     |                |                 |              |           |        |               |     |     |           | •         |             |           |              |            |     |        |                 |        |     | •             |           |     |      |     |             |     |   |
| Khartoum-Tripoli                |                    | •   | •   | •   | •   | •   | •   |            |           |          |            | •    |     |                |                 |              |           |        |               |     |     |           |           |             |           |              |            |     |        |                 |        |     |               |           |     |      |     |             |     |   |
| Lagos-Pretoria                  |                    | •   |     |     | •   | •   | •   |            |           |          |            |      |     |                |                 |              |           |        |               |     |     | •         |           |             |           |              |            |     |        |                 |        |     |               |           |     |      |     |             |     |   |
| Madras-Singapore                |                    | •   | •   | •   | •   | •   | •   |            | •         |          |            |      |     |                |                 |              |           |        |               |     |     |           |           |             |           |              |            |     |        |                 |        |     |               |           |     |      |     |             |     |   |
| Manila-Singapore                |                    | •   | •   | •   | •   | •   | •   |            |           |          |            |      |     |                |                 |              |           |        |               |     |     |           |           |             |           |              |            |     |        |                 |        |     |               |           |     |      |     |             |     |   |
| Manila-Sydney                   |                    | •   | •   | •   | •   | •   | •   |            |           |          |            |      |     |                |                 |              |           |        |               |     | •   | •         |           |             |           |              |            |     |        |                 | •      |     |               |           |     |      |     |             |     |   |
| Manila-Tokyo                    |                    |     |     | •   | •   | •   | •   |            | •         |          |            |      |     |                |                 |              |           |        |               |     | •   | •         |           |             |           | •            |            |     |        |                 |        |     | •             |           |     |      | •   |             |     |   |
| Mauritius-Nairobi               |                    | •   | •   | •   | •   | •   | •   |            |           |          |            |      |     |                |                 |              |           |        |               |     |     |           |           |             |           |              |            |     |        |                 |        |     |               |           |     |      |     |             |     |   |
| Nairobi-Tananarive              | •                  | •   | •   | •   | •   | •   | •   |            | •         |          |            |      |     |                |                 |              |           |        |               |     | •   | •         |           |             |           |              |            |     |        |                 |        |     |               |           |     |      |     |             |     |   |
| Singapore-Djakarta-Perth-Sydney |                    | •   | •   | •   | •   | •   | •   |            |           | •        |            | •    |     |                |                 |              |           |        |               |     | •   | •         |           |             |           |              |            |     |        |                 | •      |     | •             | •         |     | •    | •   |             |     |   |
| Singapore-Sydney                |                    | •   | •   | •   | •   | •   | •   |            |           | •        |            | •    |     |                |                 |              |           |        |               |     |     |           |           |             |           |              |            |     |        |                 | •      |     |               |           |     |      |     |             |     |   |
| Method(s) of wind finding       |                    |     |     |     |     |     |     |            |           |          |            |      |     |                |                 |              |           |        |               |     |     |           |           |             |           |              |            |     |        |                 |        |     |               |           |     |      |     |             |     |   |
| Doppler (spot winds)            |                    |     |     |     |     |     |     |            | •         |          |            | •    |     |                |                 |              |           |        |               | •   | •   | •         | •         | •           | •         | •            | •          |     |        | •               |        |     | •             |           |     |      |     | •           |     | • |
| Averaging between fixes         |                    |     |     |     |     |     |     |            | •         |          | •          | •    |     | •              |                 | •            |           |        | •             |     | •   |           |           |             | •         |              |            |     | •      | •               |        | •   |               |           | •   |      |     |             |     | • |

1 > 250 mb 2 after June 1963 3 75% 4 < 250 mb 5 before June 1963 6 25%



cards. A computer derived zonal wind components from the cards and programmed the curve plotter to print the values, and to mark 10-kt intervals along the vertical, on the cross-section charts. In this way we benefited from the information provided by the moving stations. Hand analysis of the zonal component of the wind (isotachs) followed.

By referring to other atlases (McDonald, 1938; van Duijnen Montijn, 1952; U.S. Weather Bureau, 1957; U.S. Navy, 1966) we were able to confidently extend analyses to the surface.

In our analysis of the field of potential temperature (isentropes), we used the publication by Goldie, Moore, and Austin (1958) as a "first guess." It was especially valuable in helping us to locate the tropopause.

Minor discrepancies occurred along longitudes with considerable zonal gradients where stations lay some distance from the cross-section meridian. We then, by referring to the constant pressure-level charts, made the analyses fit conditions along the meridian.

Corresponding constant pressure-level and cross-section charts were carefully compared to ensure an internally consistent three-dimensional presentation and to identify and correct data errors. However, we carefully avoided unnecessary smoothing, since smoothing is often synonymous with imposing preconceived notions on the analysis. Data over the tropical Indian Ocean is too scanty and our knowledge too meager to justify doing this.

#### AVAILABILITY OF DATA

Some investigators will wish to make their own analyses and interpretation of the data used in this atlas. From

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they can obtain at cost

1. Long-term station averages and 5-degree square averages which are also reproduced on the atlas charts.
2. For each month of 1963 and 1964 at 50 mb intervals for each aerological station: means of pressure height, temperature and dew point, and as available, their standard deviations, resultant winds, and steadiness.

These data can be supplied on magnetic tape, punch cards, or microfilm.

#### INDIVIDUAL CHARTS

On each chart, only two sets of isopleths can be conveniently displayed, whereas more than two variables were averaged. Thus, to facilitate atlas users making their own analyses, all the averaged variables have been printed on the charts. Since entering the data by typesetting or drafting would have been error ridden as well as unjustifiably expensive, we chose a new method which holds much promise for future atlas design.

The punch card decks previously prepared for the Benson-Lehner curve plotter were transferred with appropriate translation programs to magnetic tape. The tape was then run through a Calcomp 718 plotter which drew the digits of each data cluster at the correct chart location.

The color scheme, line weights, type sizes, and styles have been chosen to provide maximum information with minimum clutter. The more important isopleths spring first to the eye while scrutiny readily reveals all the other data entered on the charts. Density of observations enables the reader to readily evaluate reliability of the analyses.

Lack of space prevented all the data used in the analyses from being printed in the Atlas.

Chart No. 1 locates all the fixed stations for which averages were obtained.

#### CONSTANT PRESSURE LEVELS

(Charts 2-7, 12-17, 22-27, 32-37, 42-47, 52-57,  
62-67, 72-77, 82-87, 92-97, 102-107, 112-117)

The box in the lower center of each chart contains the title, defines the isopleths, and defines the numerical data listed at the fixed stations and at average locations within 5-degree squares.

Where fewer than five aircraft wind observations contributed to a 5-degree square average, the information has not been printed. Similarly, the average of fewer than three research aerological soundings in a 5-degree square has not been printed. Overlapping has been avoided by giving fixed stations priority over moving stations.

Widespread demand led to inclusion of charts for the 100 mb level. However, scanty data prevented definitive analysis of the speed field.

Mean resultant winds and mean pressure-heights appear to be reasonably well aligned up to 500 mb, even in low latitudes. This is largely because averaging tends to cancel ageostrophic components (Worthley, 1959). Convenience and usage dictated the choice of knots to denote wind speed.

Wind steadiness %  $((\text{mean resultant wind}/\text{mean wind}) \times 100)$  is both easier to calculate and gives much the same information as standard deviation.

Above 500 mb, individual temperature and pressure errors accumulate with height. Where different stations use different makes of radiosonde, the resultant errors in pressure-height gradients will not be random (World Meteorological Organization, 1957), and even after averaging will remain significant in low latitudes.

Most of the humidity sensors are inaccurate below 0°C. Therefore, dew-point averages for levels above 500 mb are of limited value.

#### LONGITUDINAL CROSS SECTIONS

(Charts 8-11, 18-21, 28-31, 38-41, 48-51, 58-61,  
68-71, 78-81, 88-91, 98-101, 108-111, 118-121)



The box in the upper left-hand corner of each chart contains the title, defines the isopleths, and defines the numerical data listed at the fixed stations.

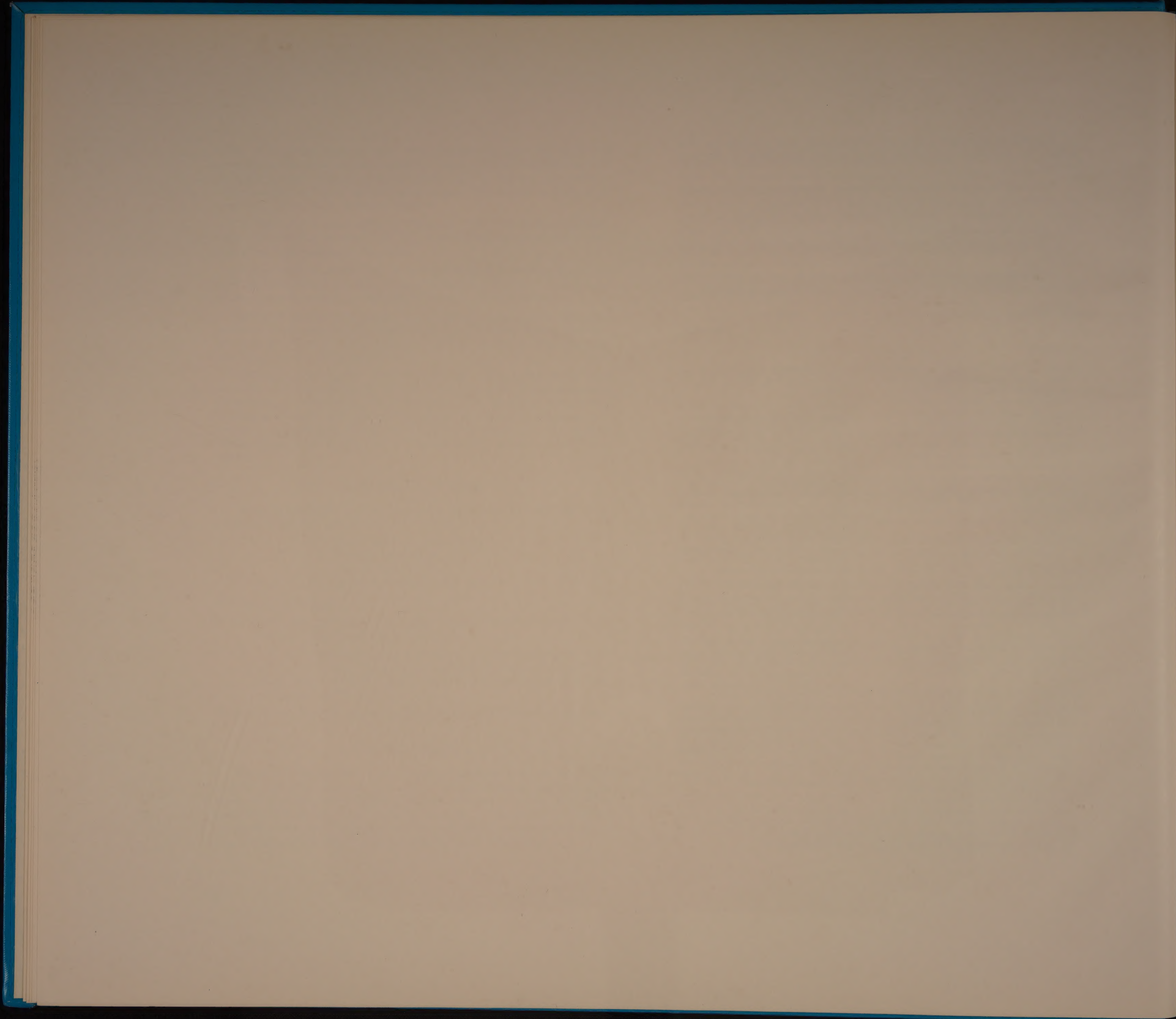
Although locations of observing stations determined what longitudes we selected for cross sections, the sections are fortunately fairly evenly spaced and represent a variety of regimes: continental (30E), Northern Hemisphere continental and Southern Hemisphere oceanic (73E and 100E), and Northern Hemisphere oceanic and Southern Hemisphere continental (140E).

Although some stations regularly made soundings into the stratosphere, the data were too few to justify extending the analysis beyond 100 mb.

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# Contents

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| Cross Sections .....           | 38-41         |  |
| MAY                            |               |  |
| Constant Pressure Levels ..... | 42-47         |  |
| Cross Sections .....           | 48-51         |  |
| JUNE                           |               |  |
| Constant Pressure Levels ..... | 52-57         |  |
| Cross Sections .....           | 58-61         |  |
| JULY                           |               |  |
| Constant Pressure Levels ..... | 62-67         |  |
| Cross Sections .....           | 68-71         |  |
| AUGUST                         |               |  |
| Constant Pressure Levels ..... | 72-77         |  |
| Cross Sections .....           | 78-81         |  |
| SEPTEMBER                      |               |  |
| Constant Pressure Levels ..... | 82-87         |  |
| Cross Sections .....           | 88-91         |  |
| OCTOBER                        |               |  |
| Constant Pressure Levels ..... | 92-97         |  |
| Cross Sections .....           | 98-101        |  |
| NOVEMBER                       |               |  |
| Constant Pressure Levels ..... | 102-107       |  |
| Cross Sections .....           | 108-111       |  |
| DECEMBER                       |               |  |
| Constant Pressure Levels ..... | 112-117       |  |
| Cross Sections .....           | 118-121       |  |







# Charts





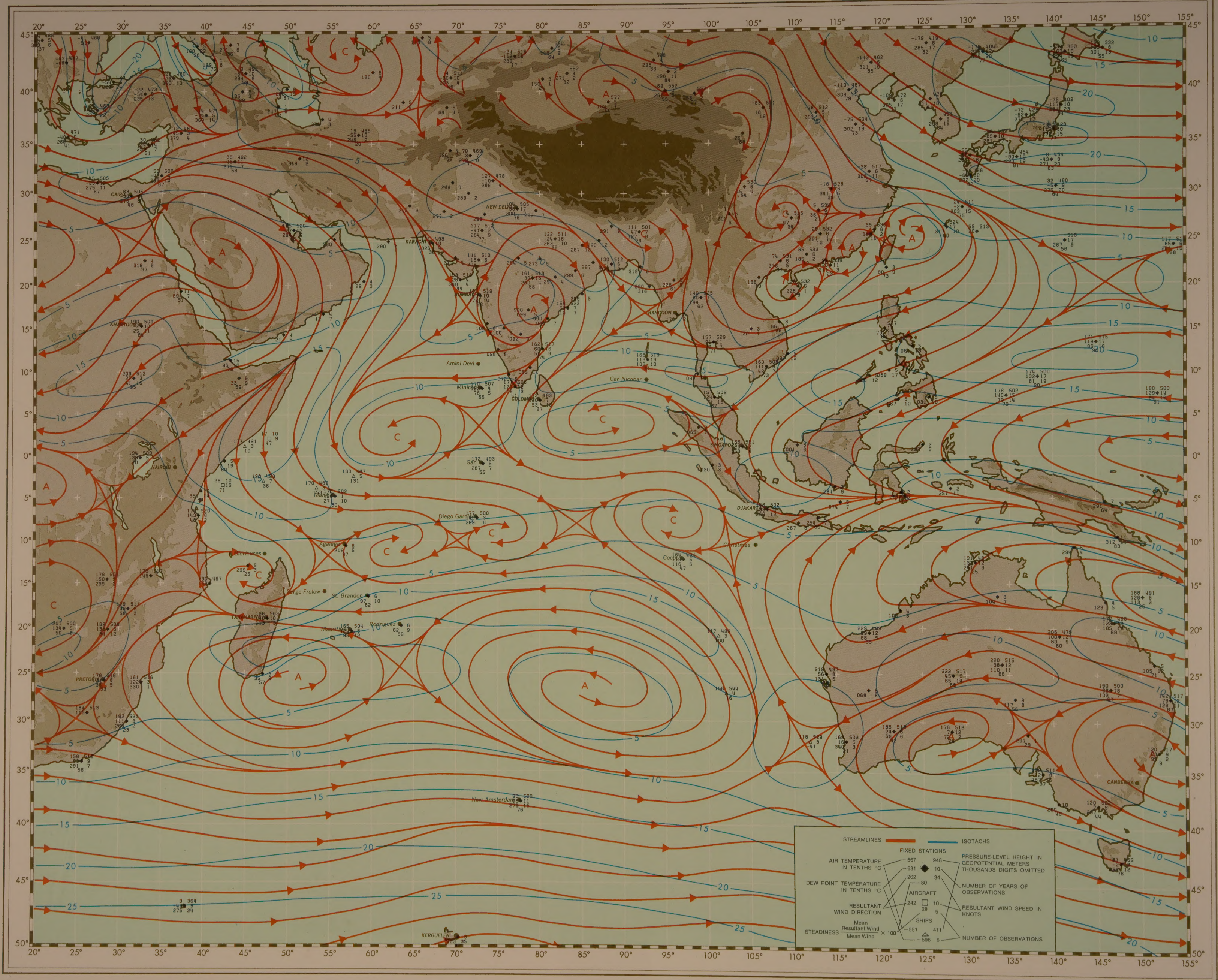


## STATION LOCATOR

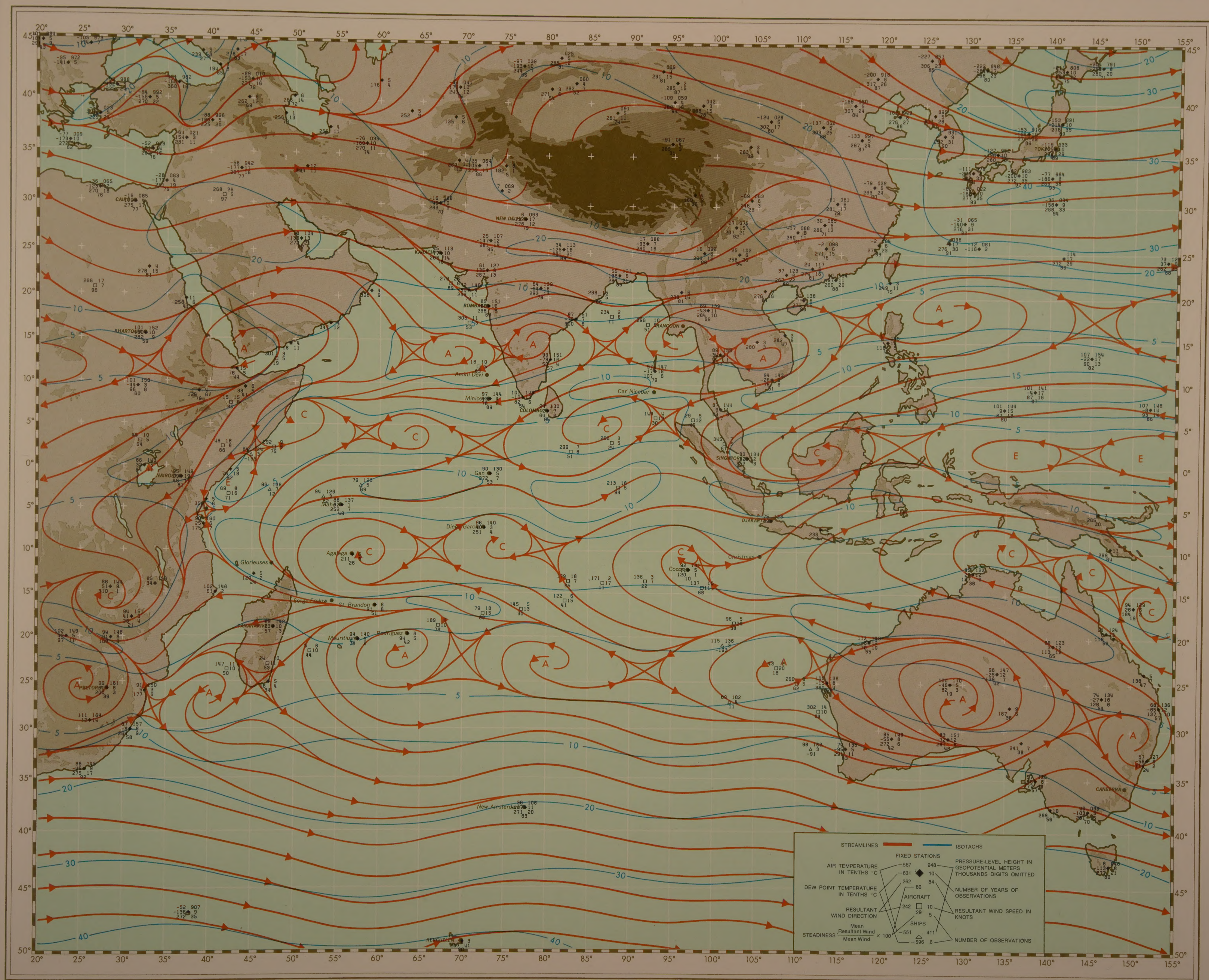
### Chart 1



# JANUARY 850 mb Chart 2

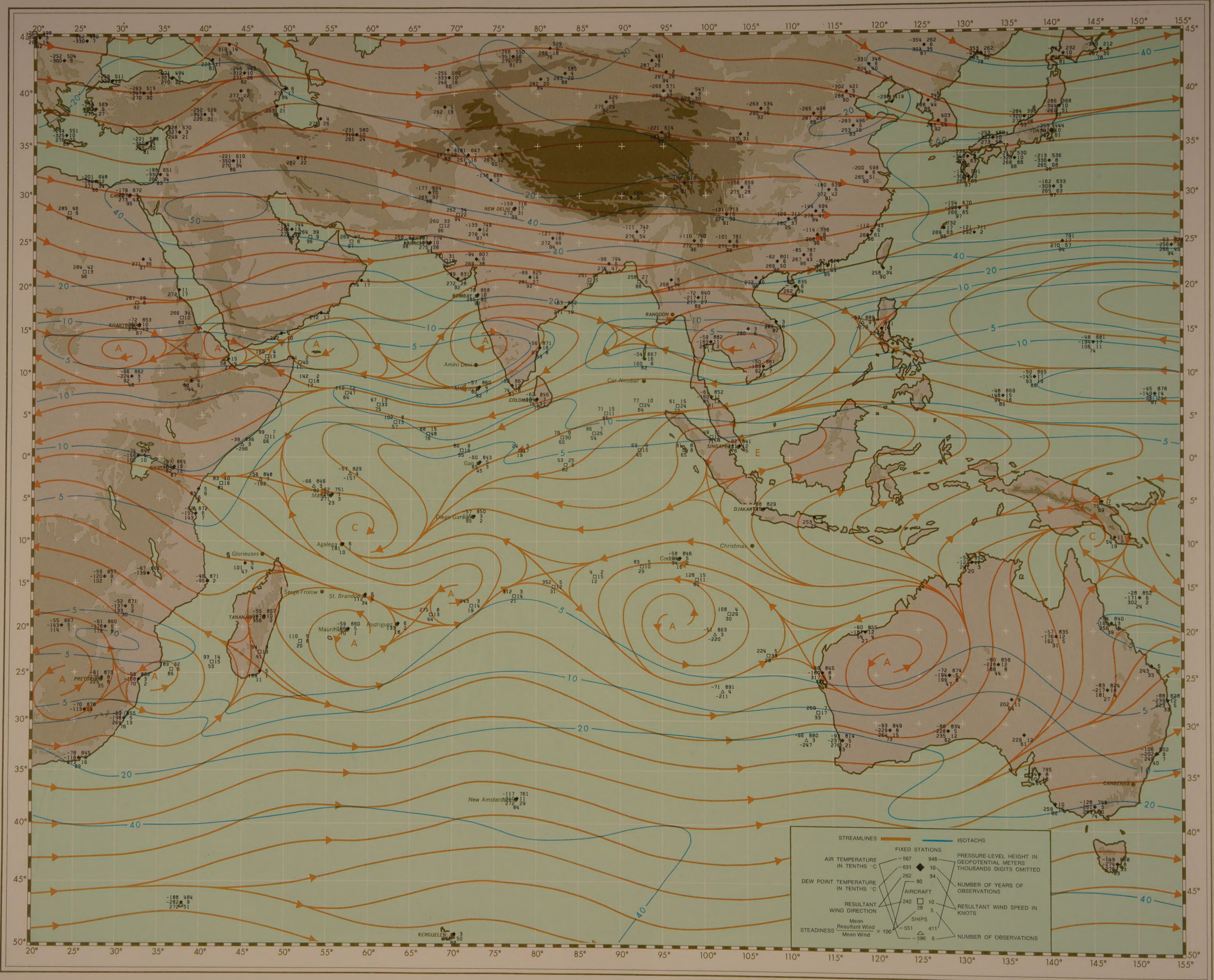






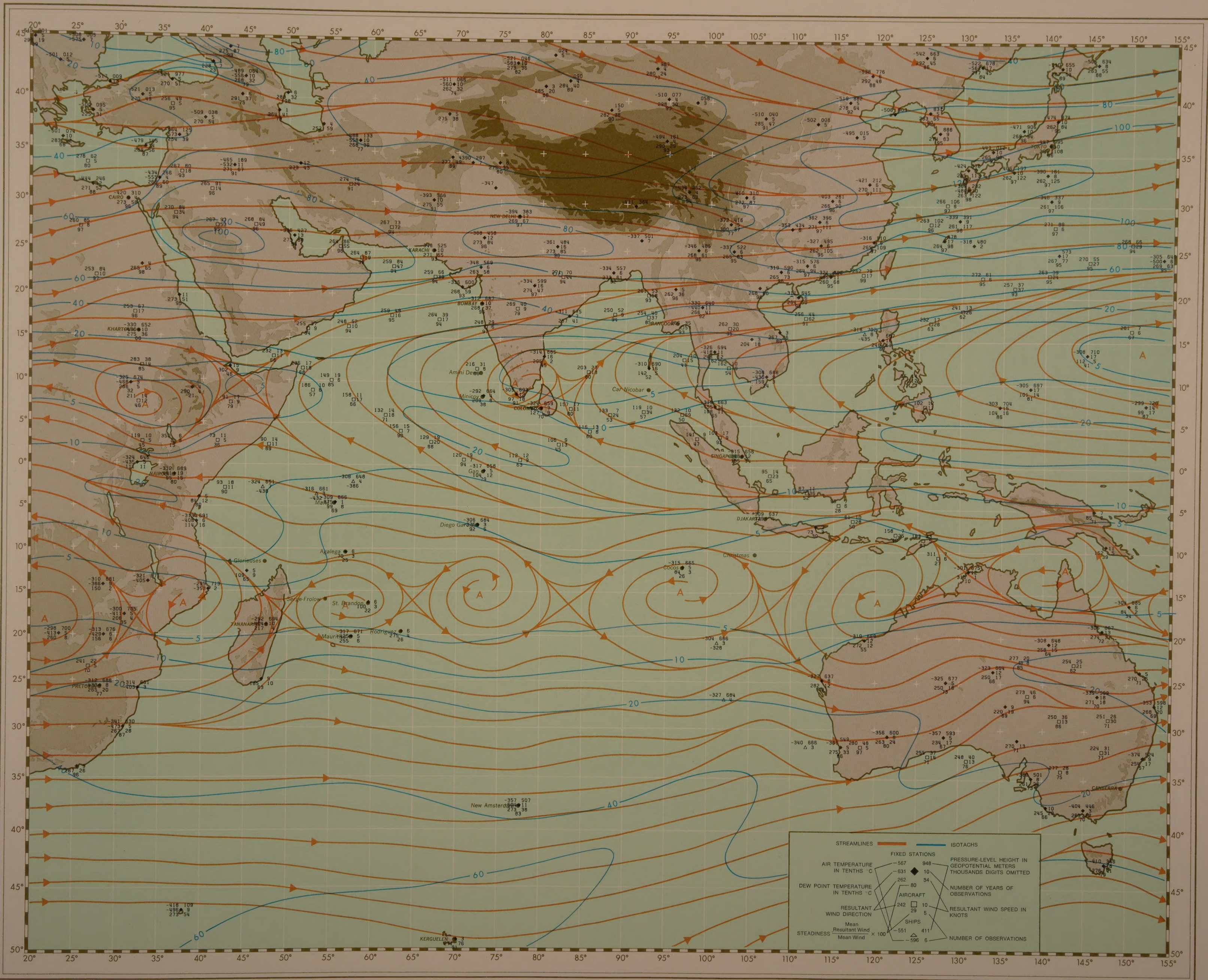


# JANUARY 500 mb Chart 4



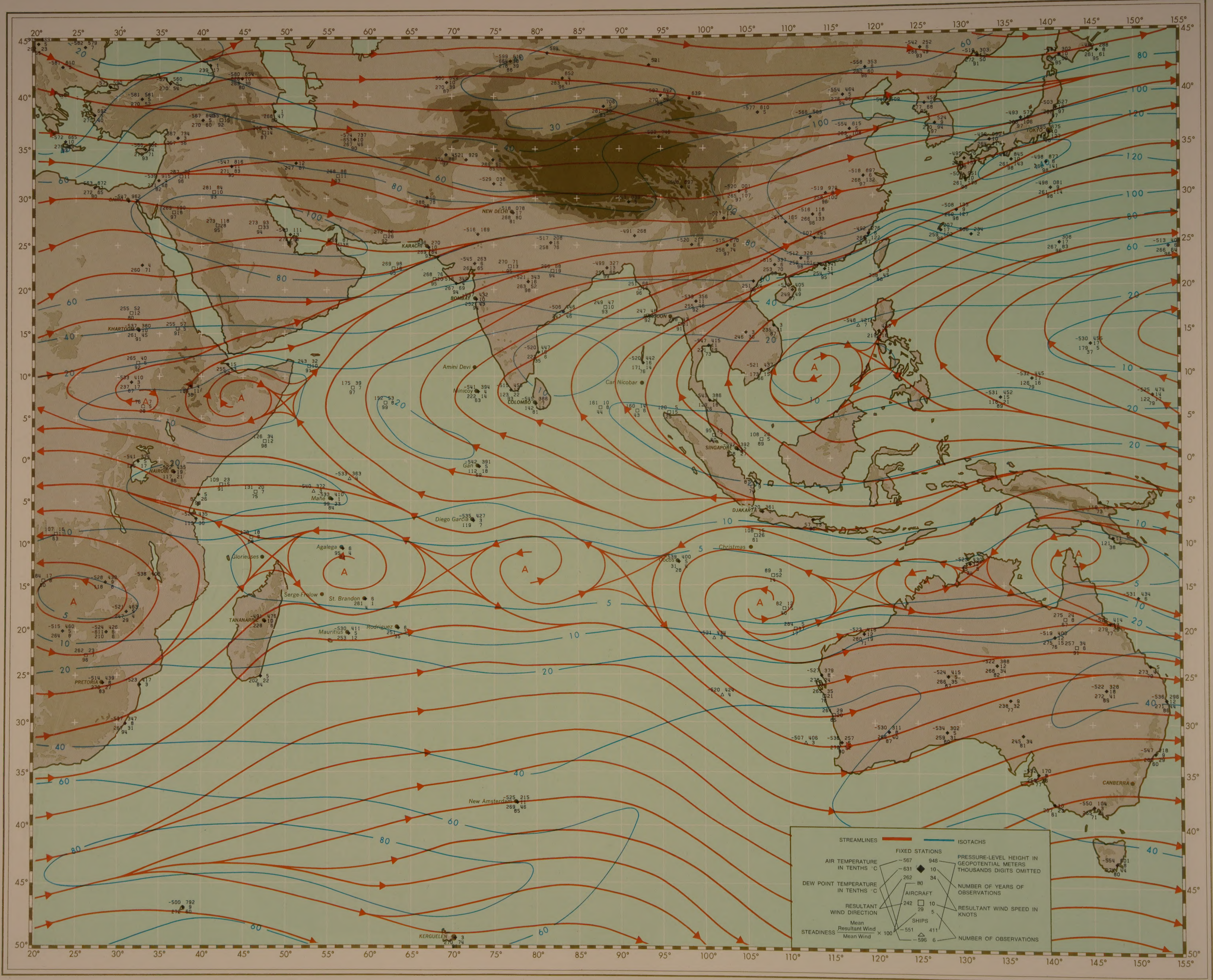


# JANUARY 300 mb Chart 5



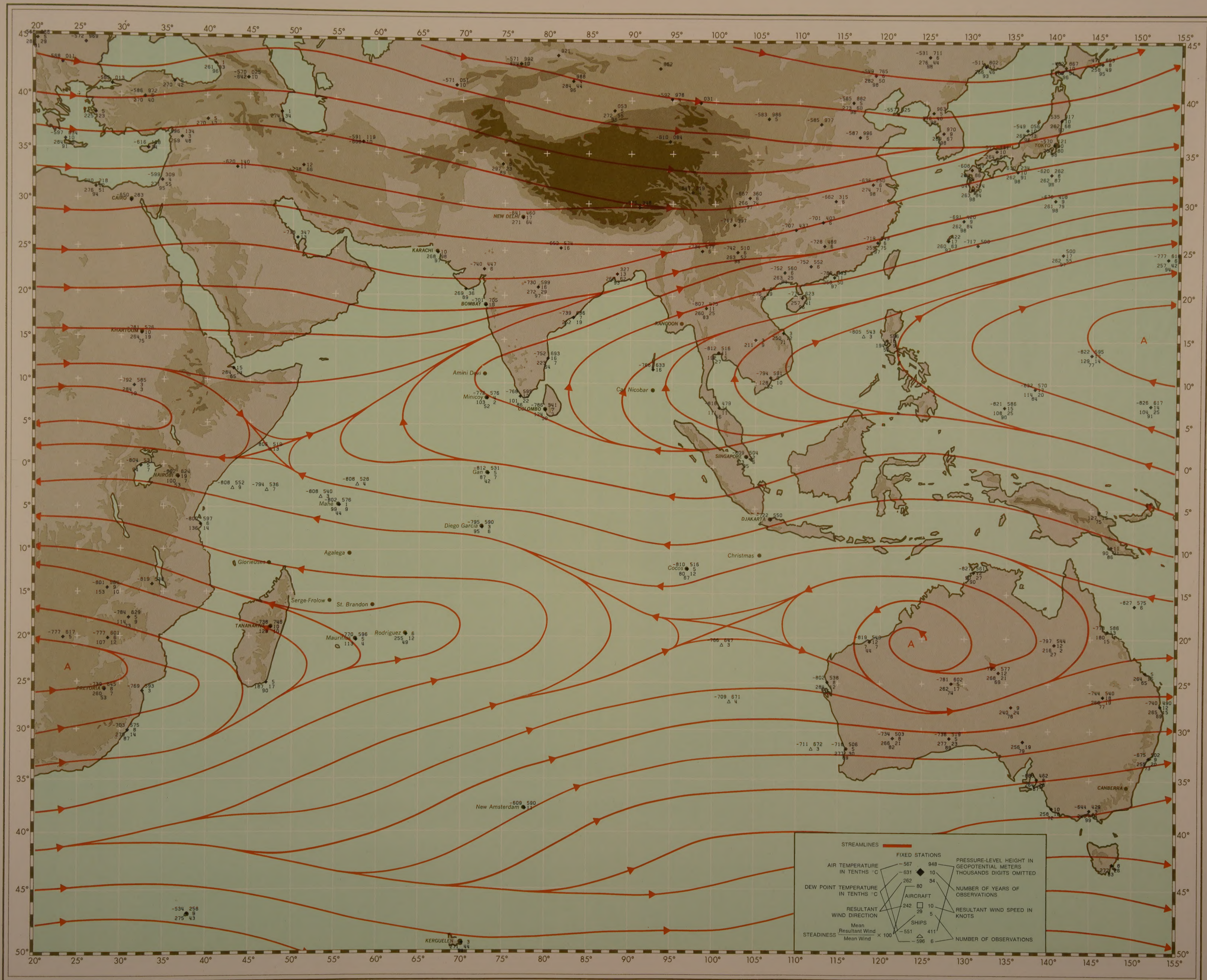


# JANUARY 200 mb Chart 6



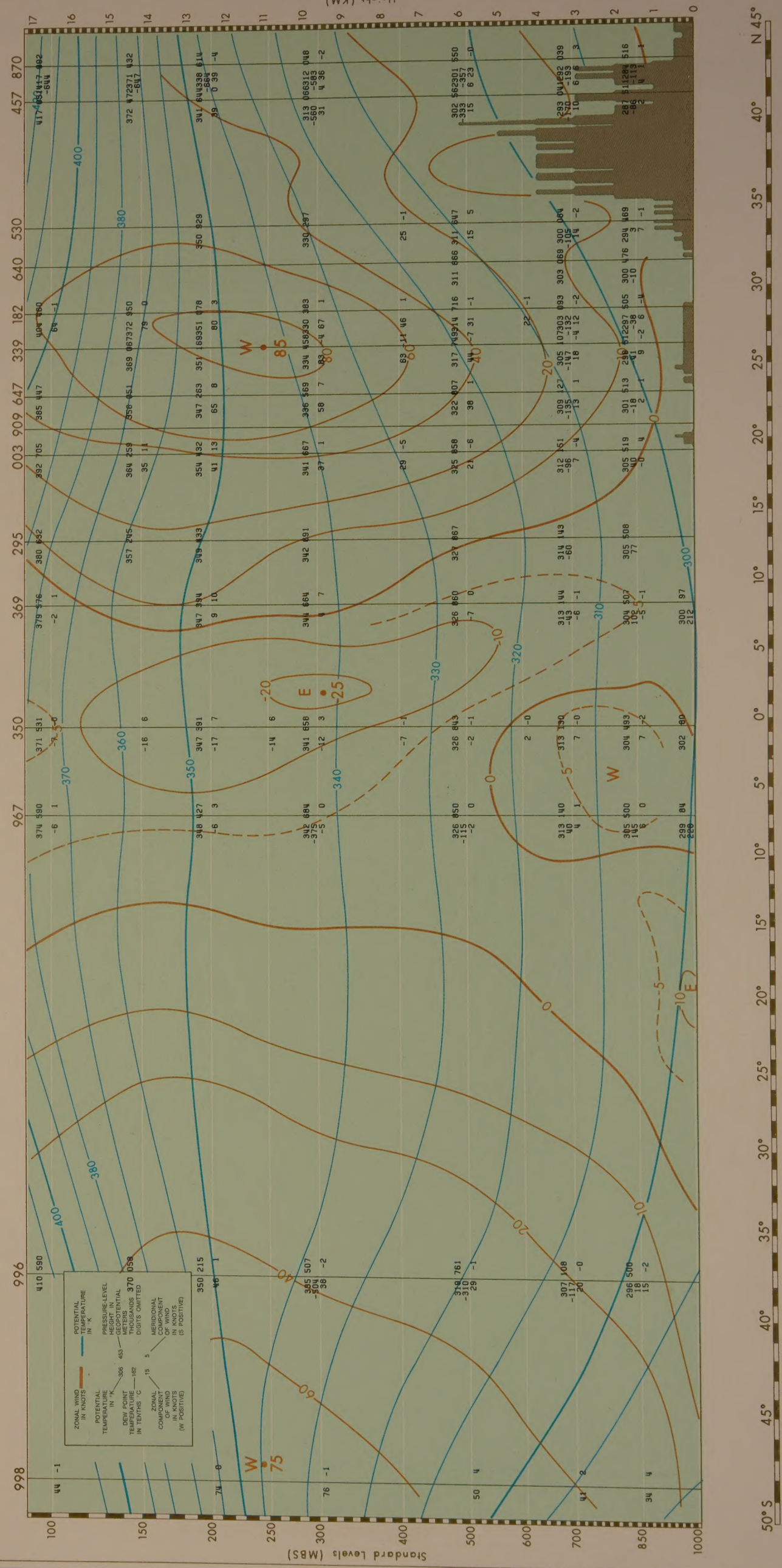
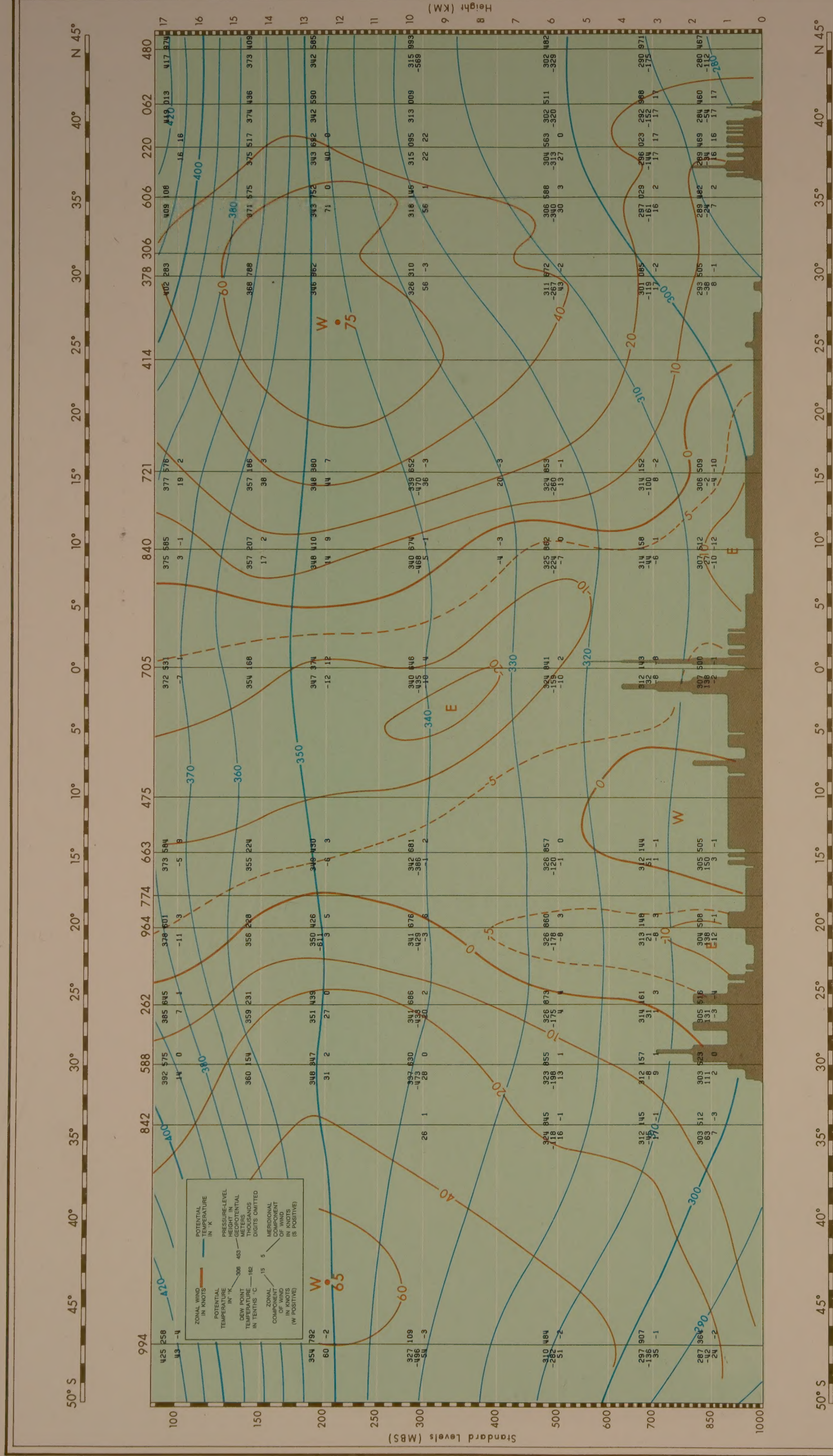


# JANUARY 100 mb Chart 7

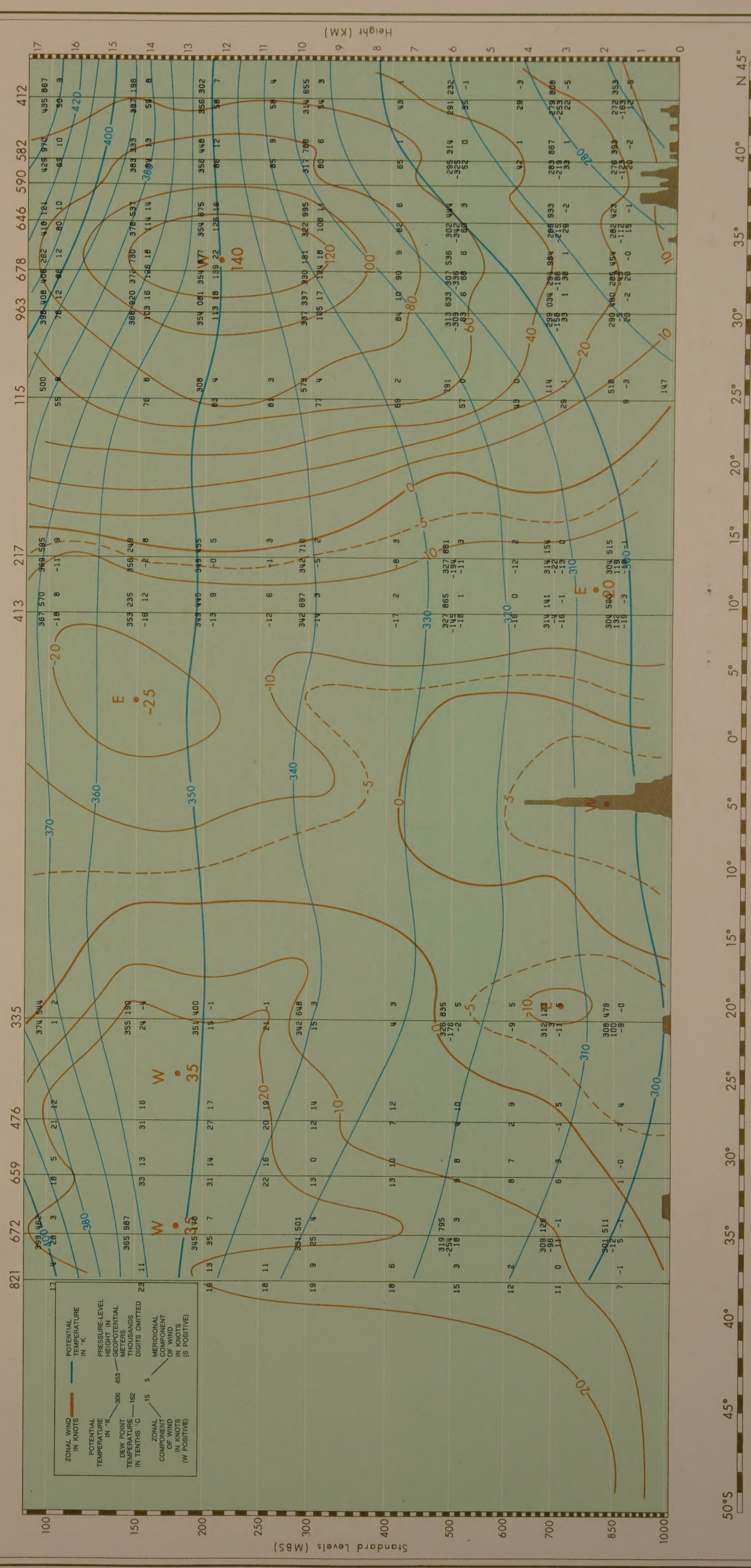
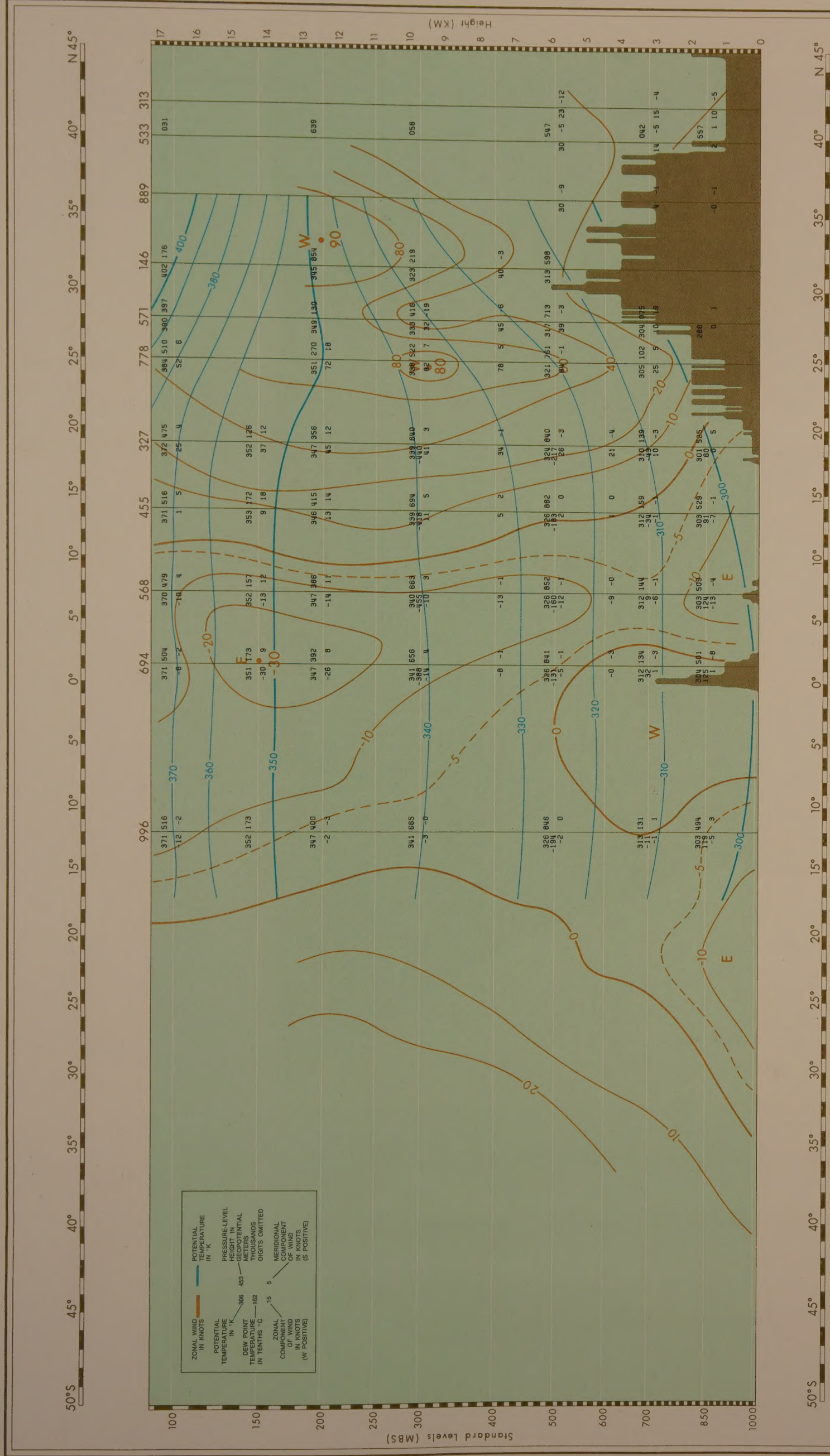




# JANUARY 30 E Chart 8



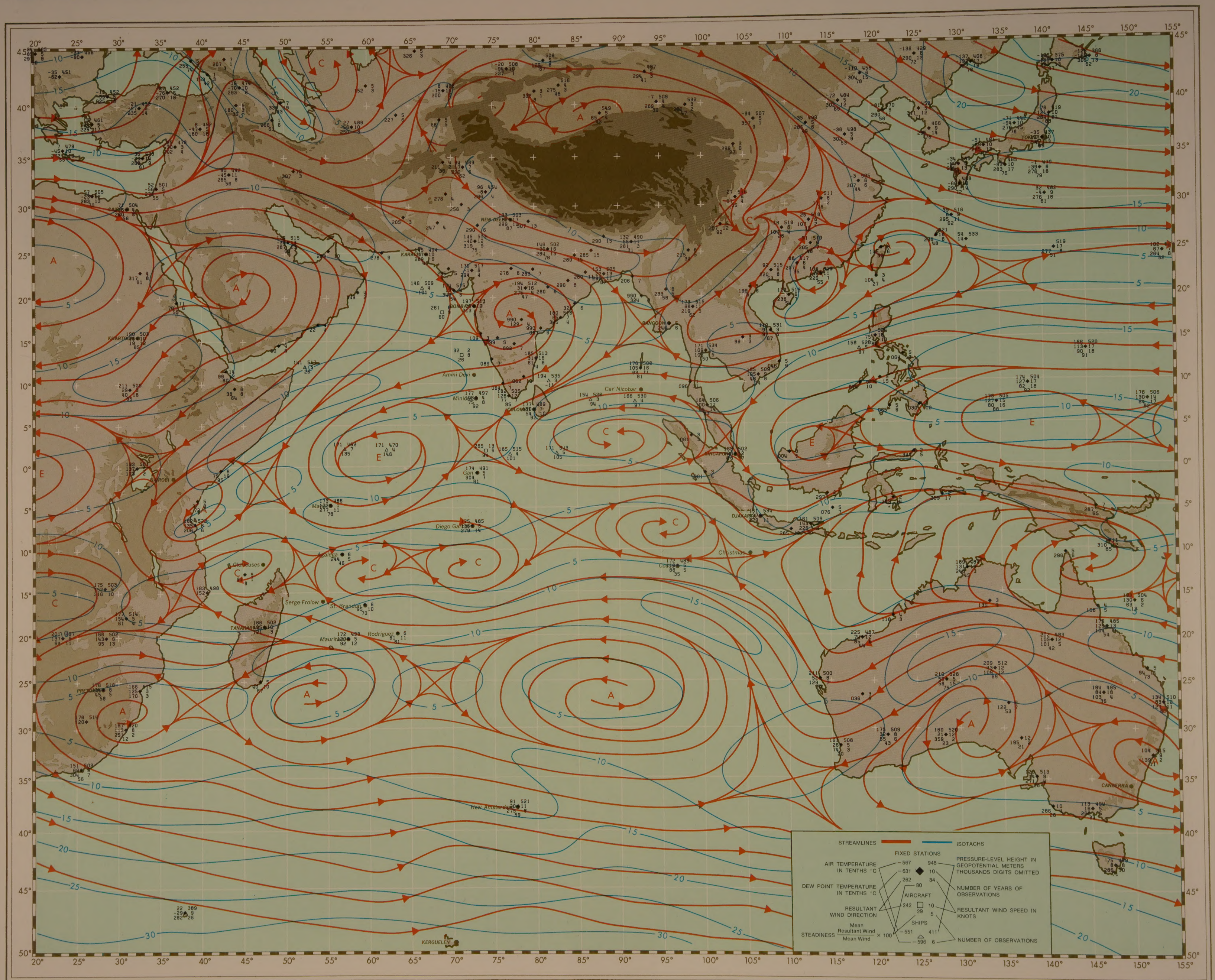






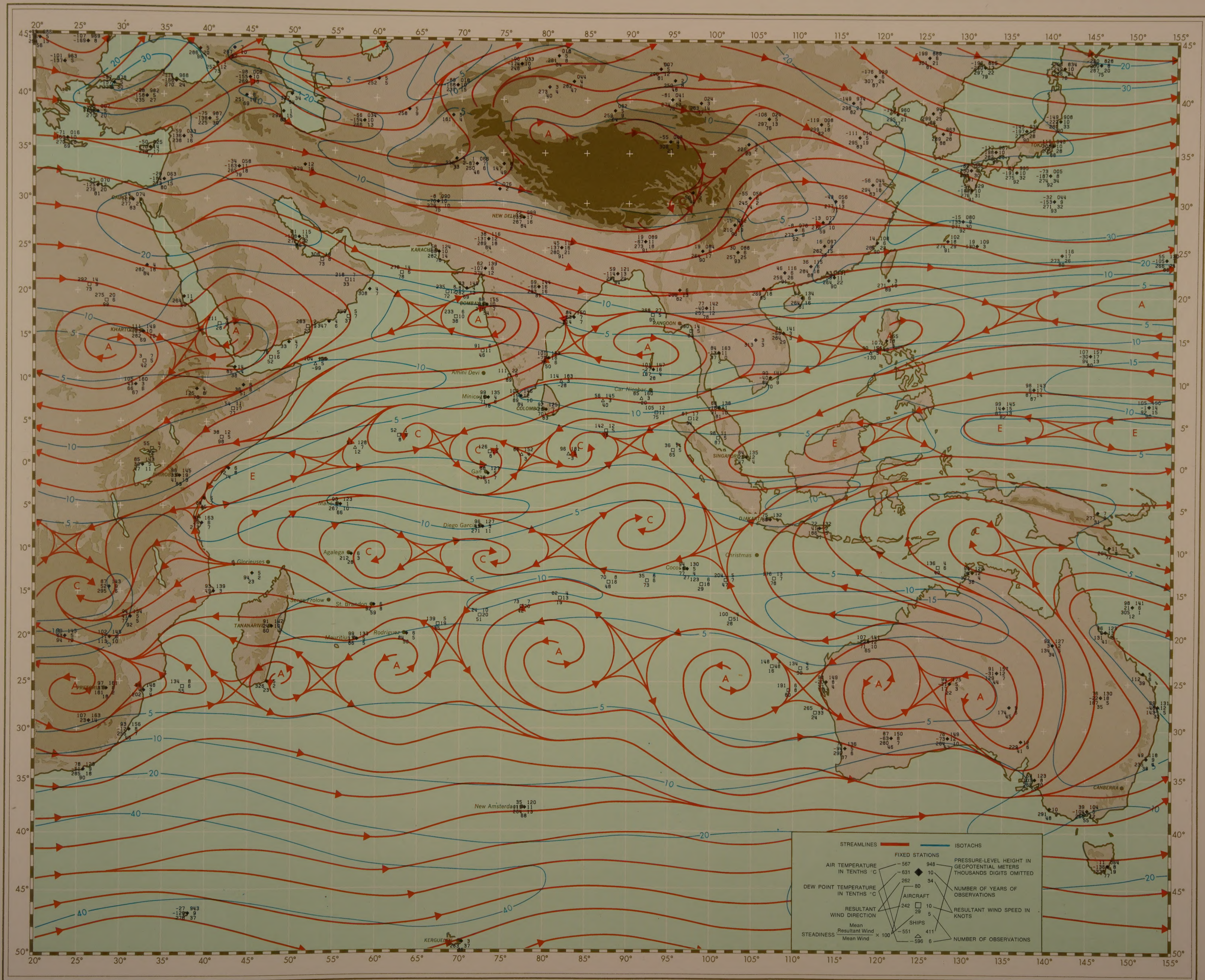
FEBRUARY 850 mb

Chart 12



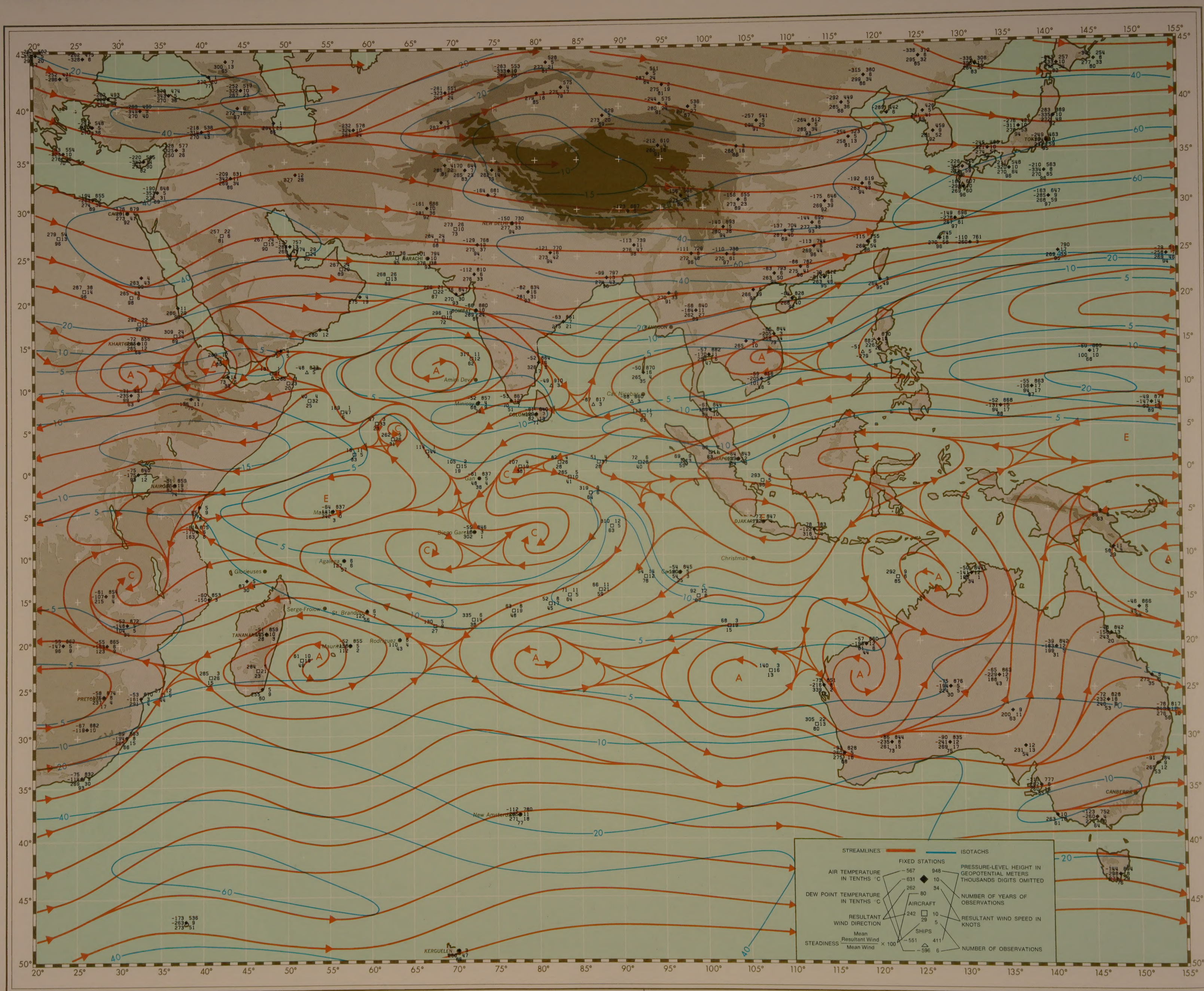


# FEBRUARY 700 mb Chart 13

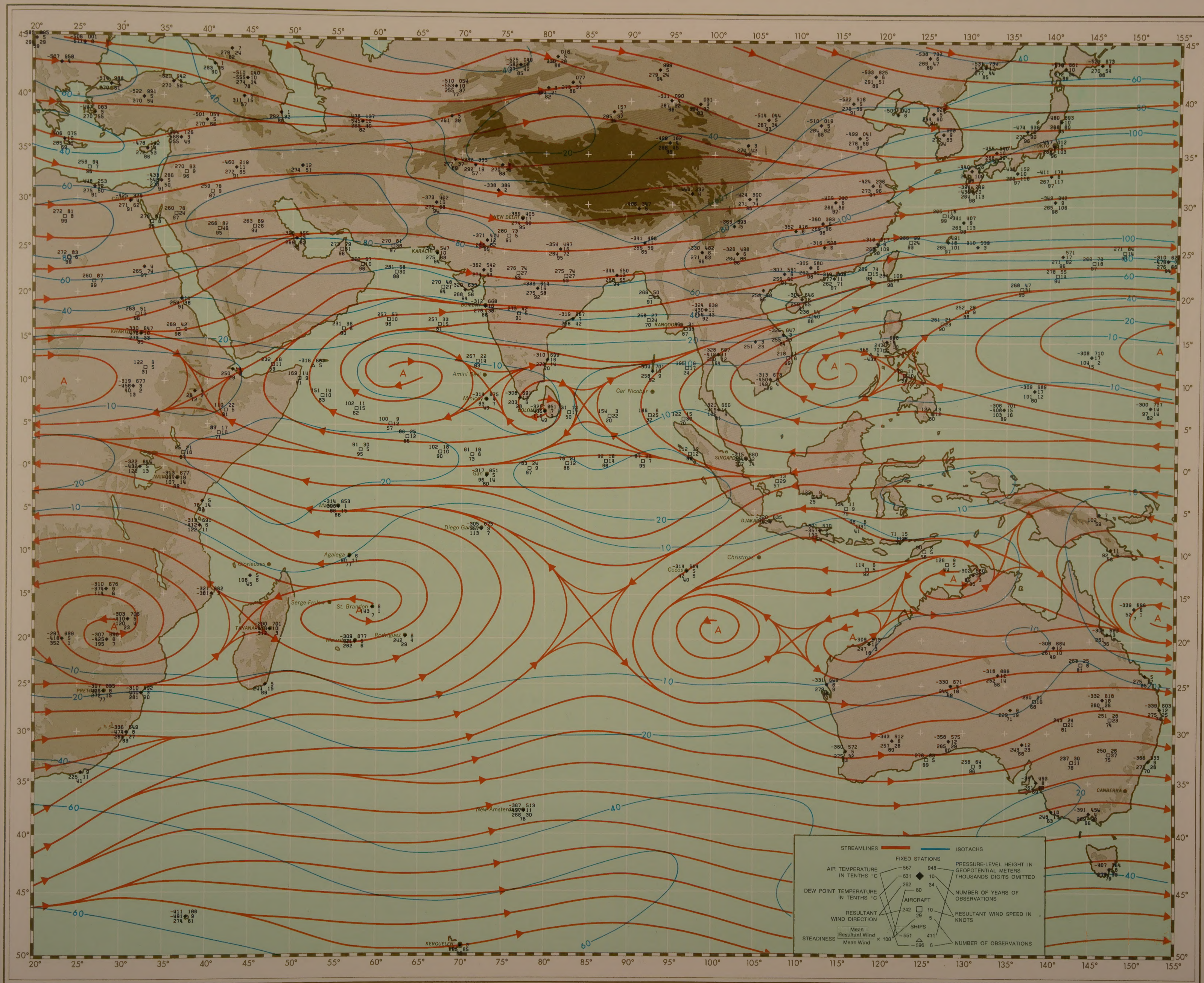




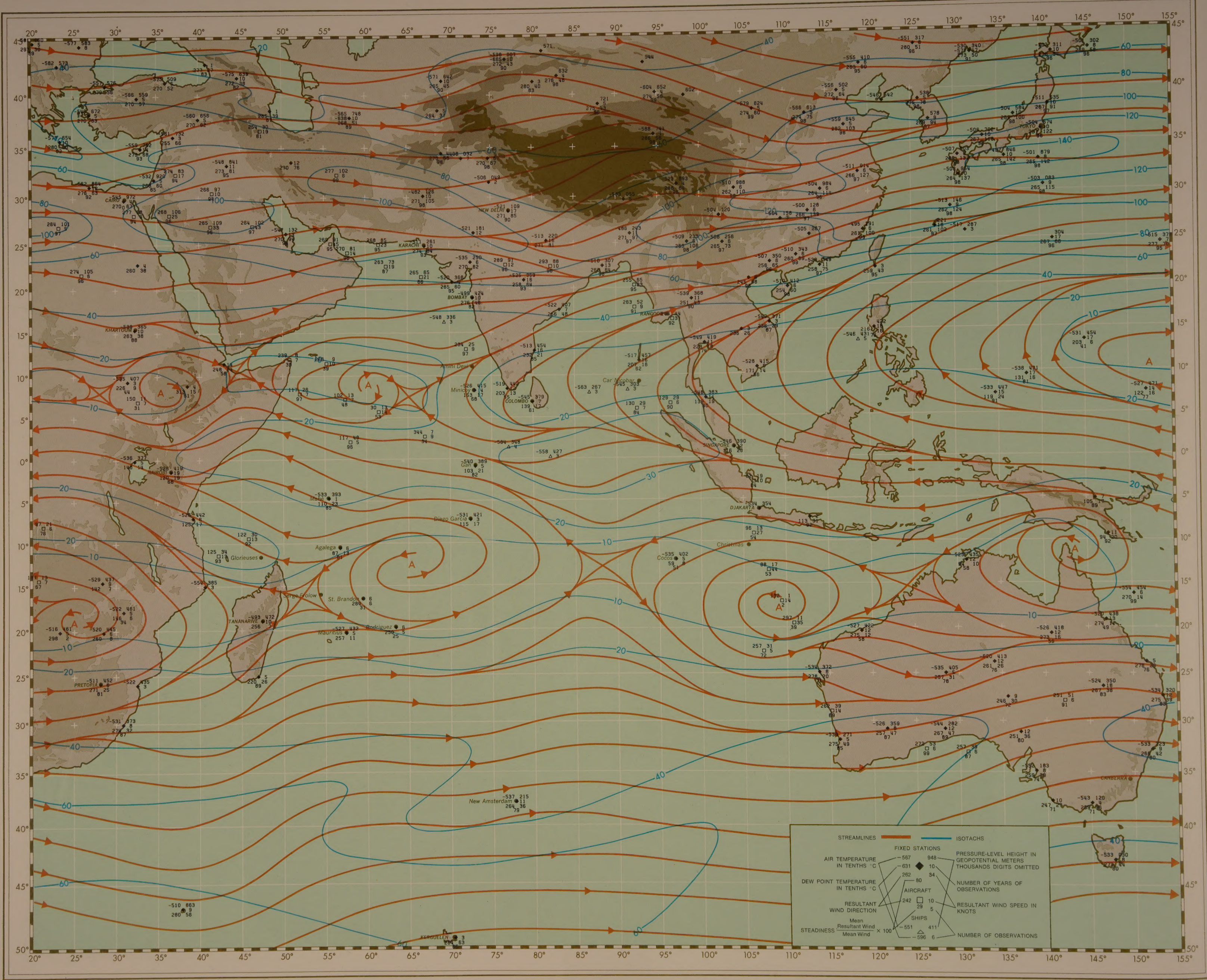
# FEBRUARY 500 mb Chart 14





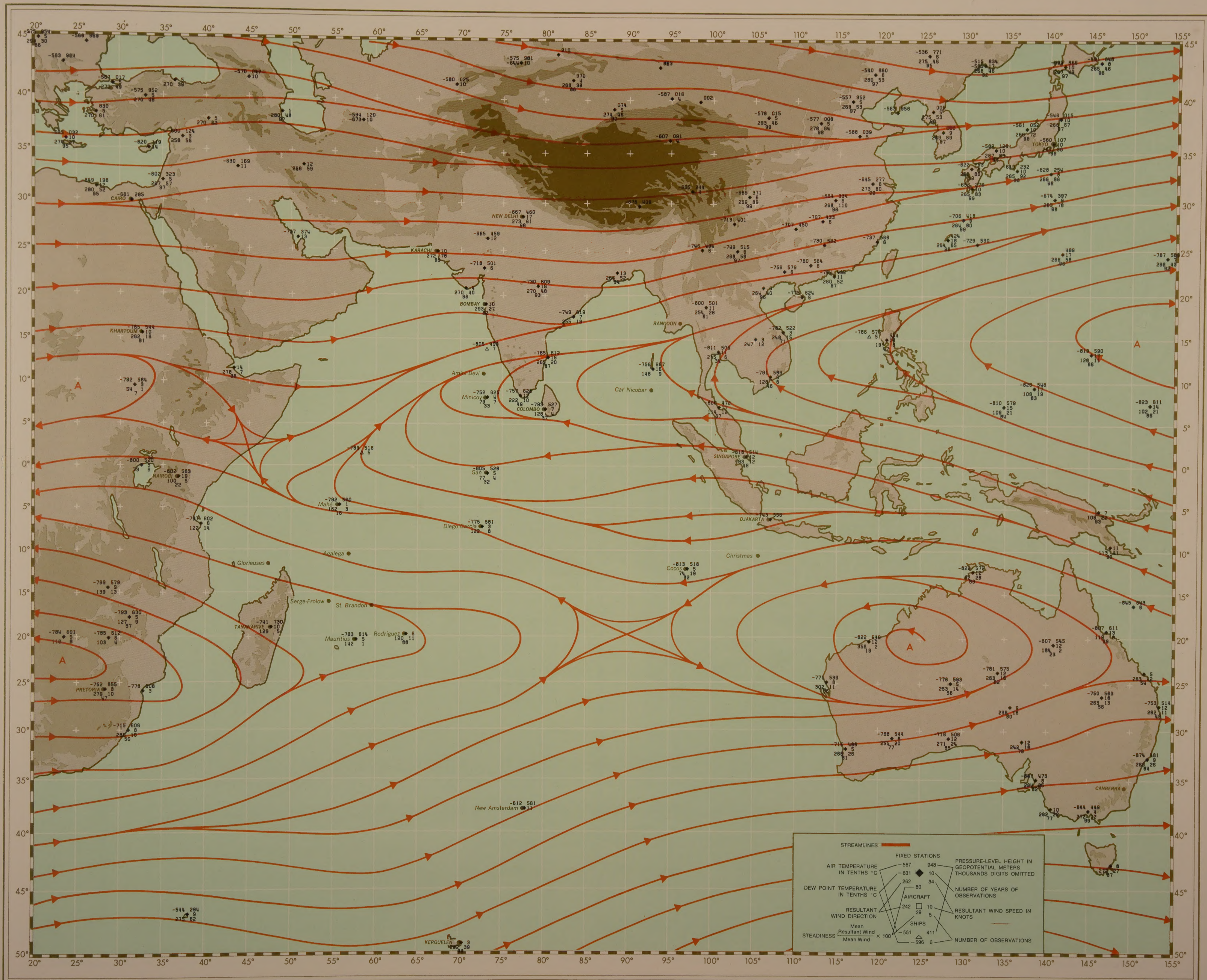






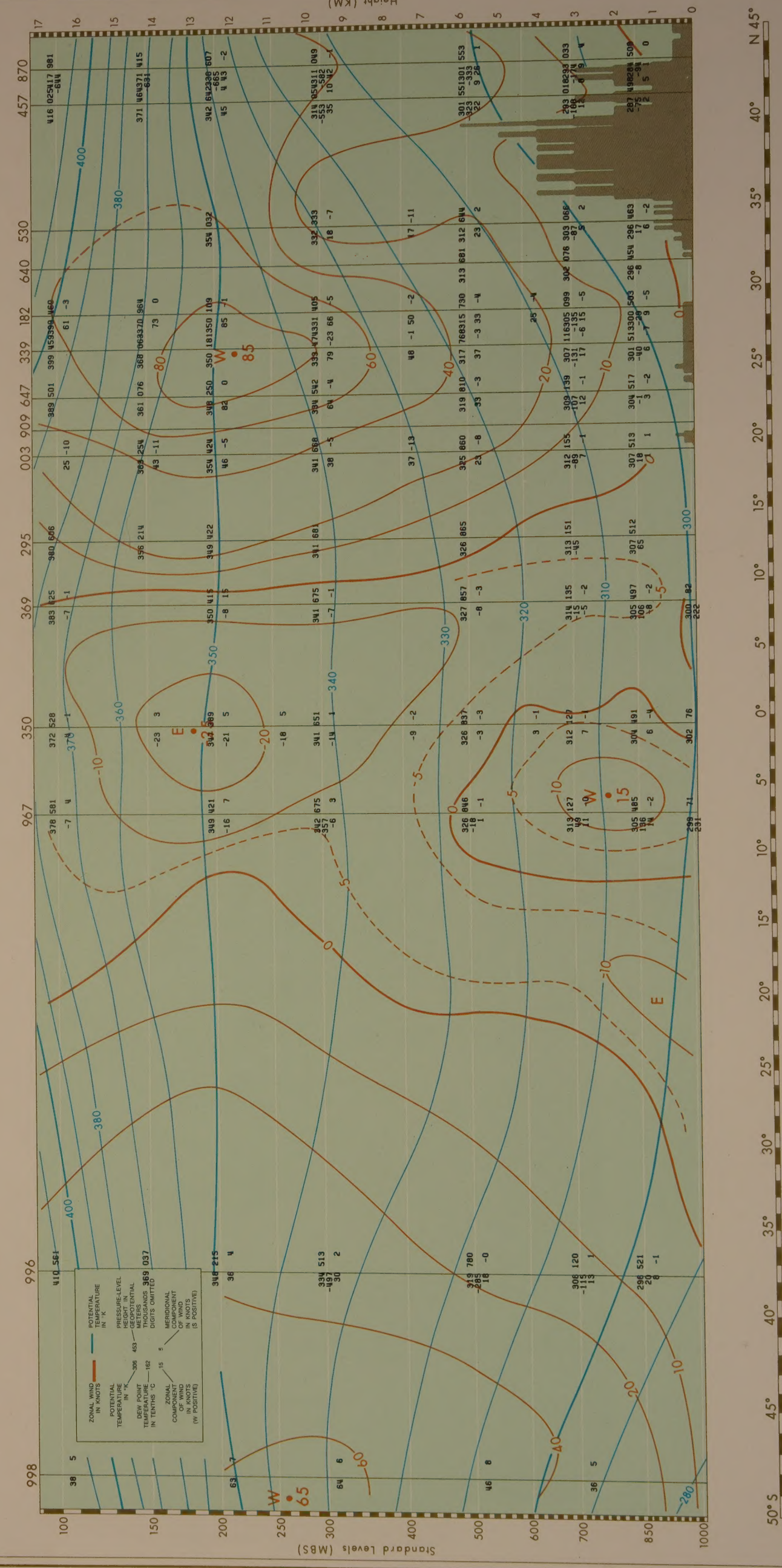
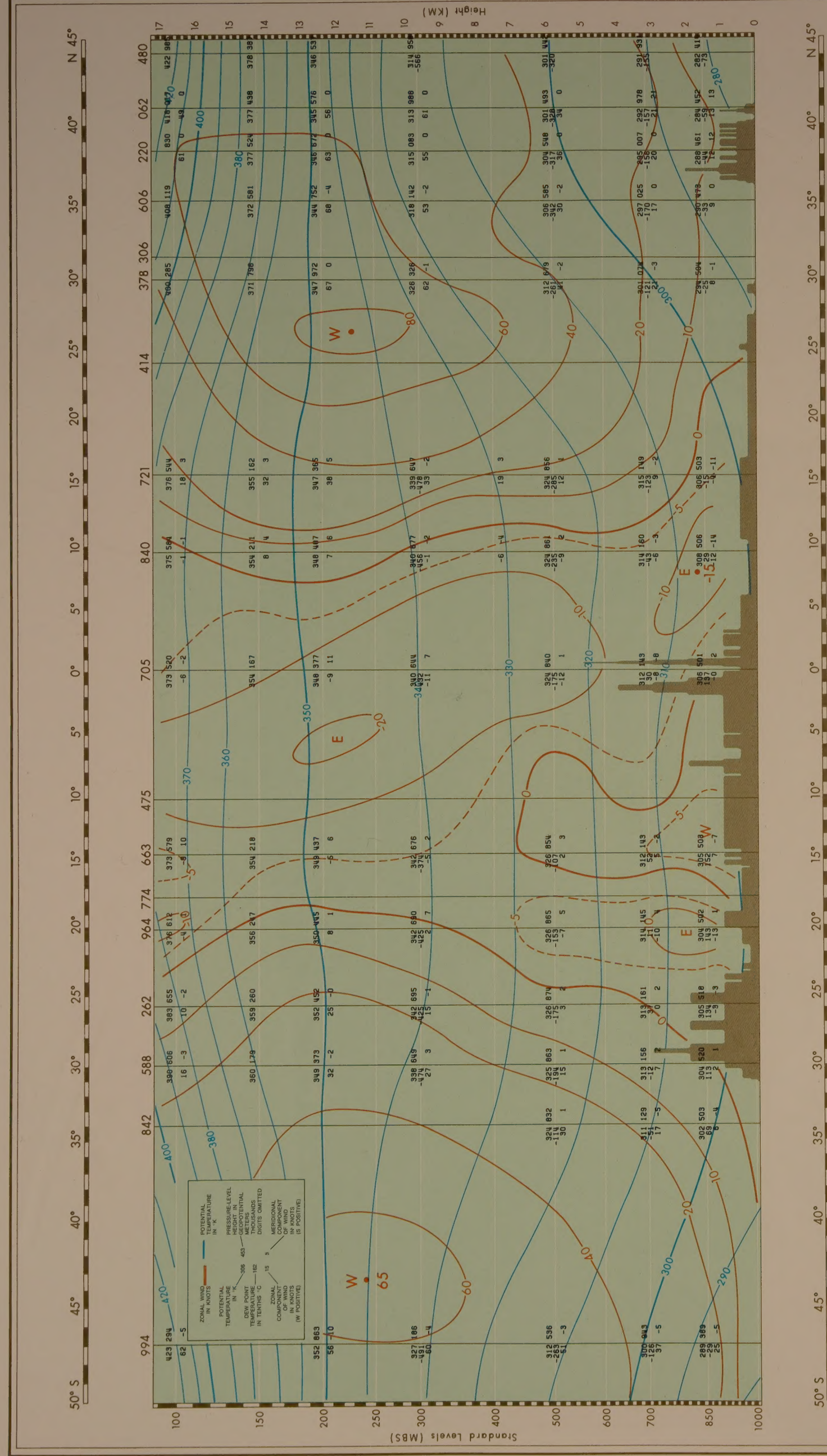


# FEBRUARY 100 mb Chart 17

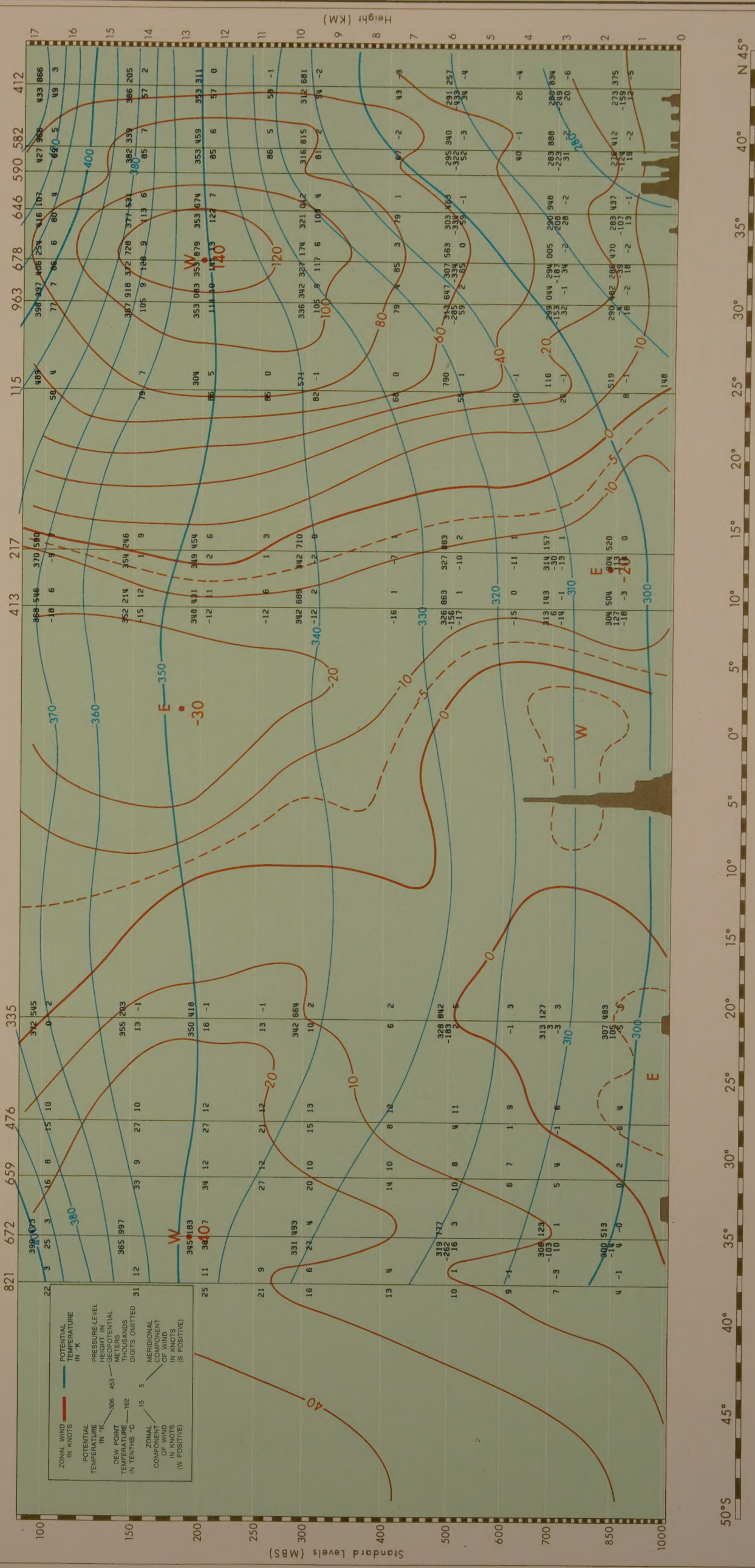
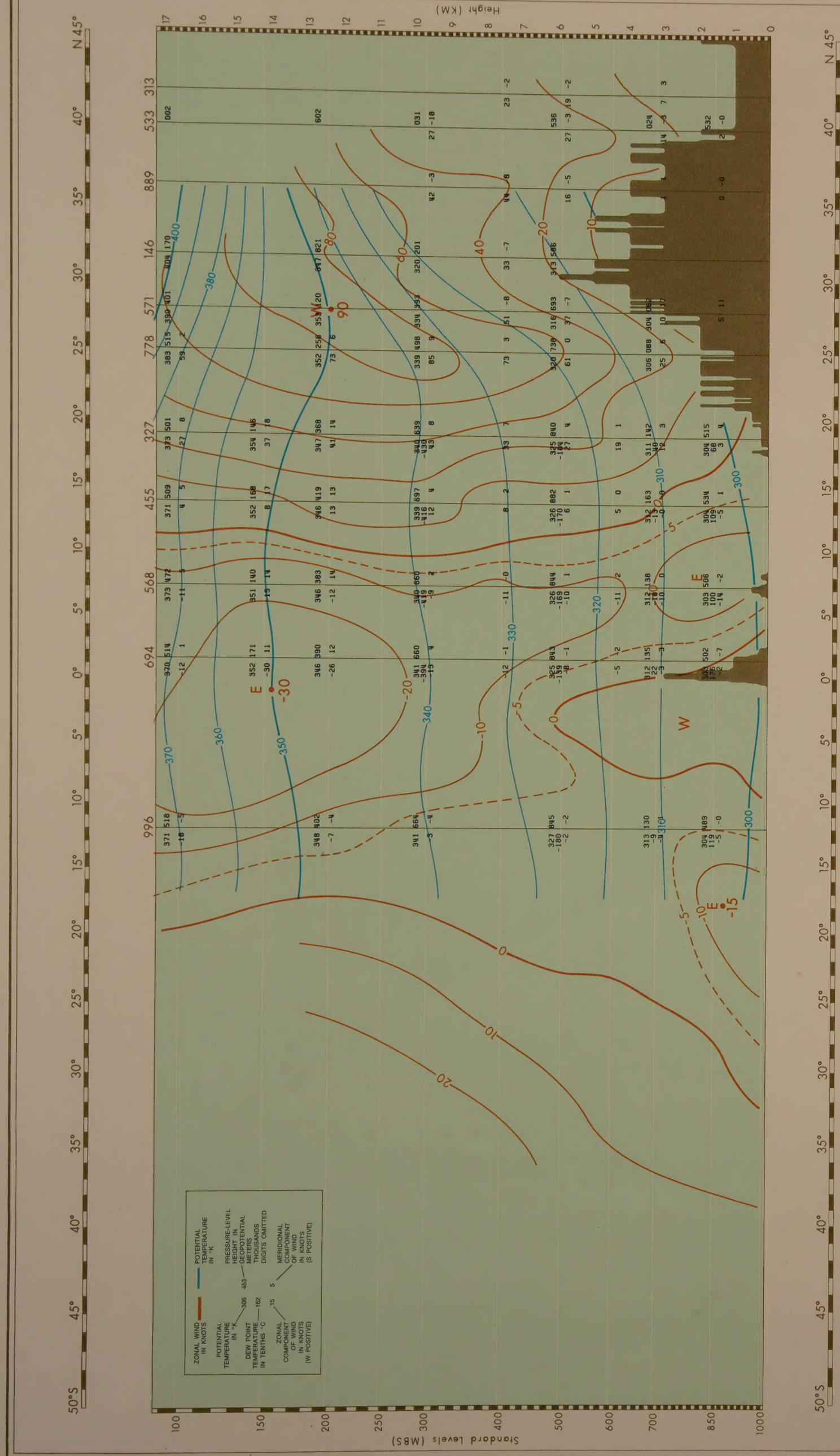




## FEBRUARY 30 E Chart 18

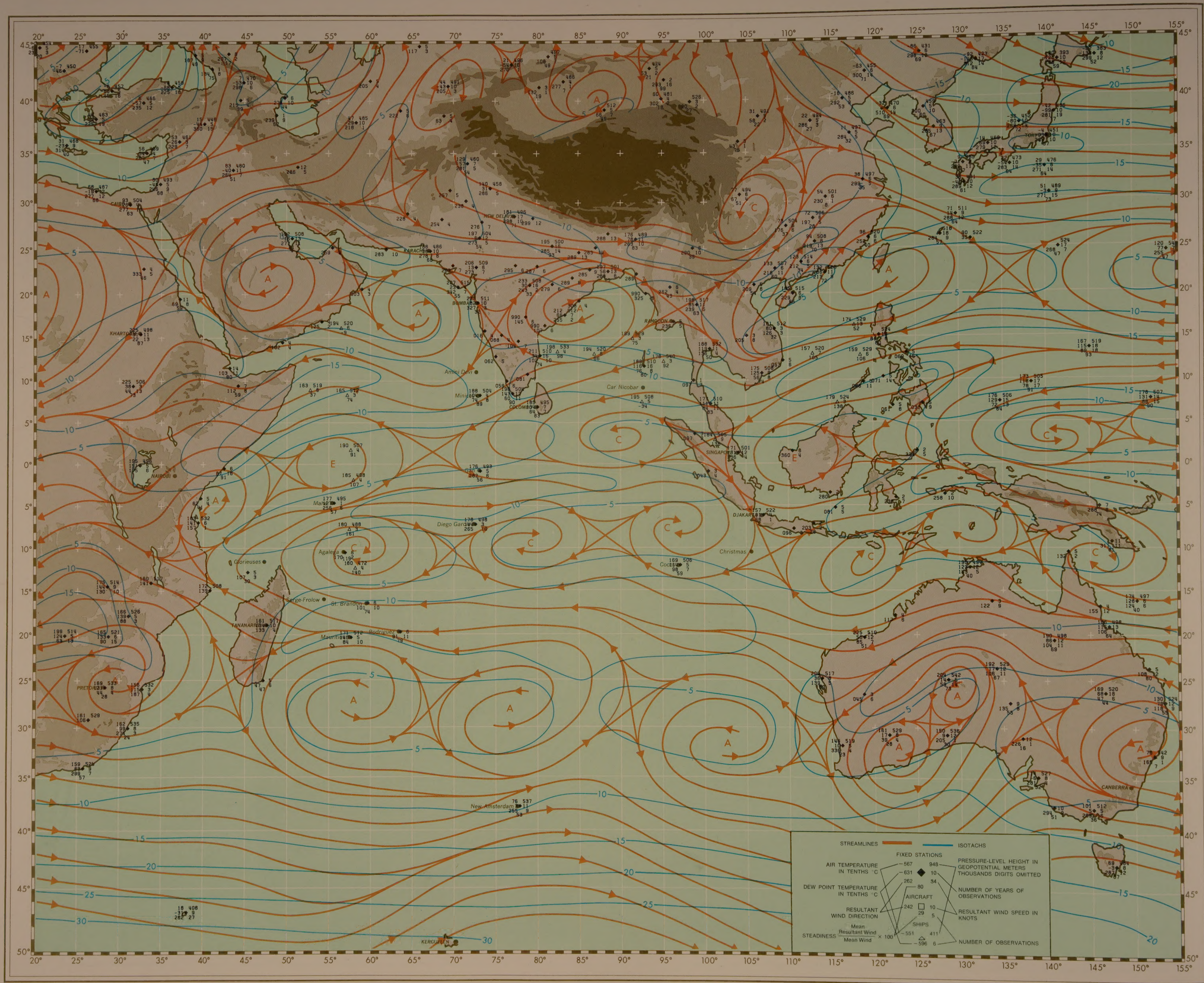




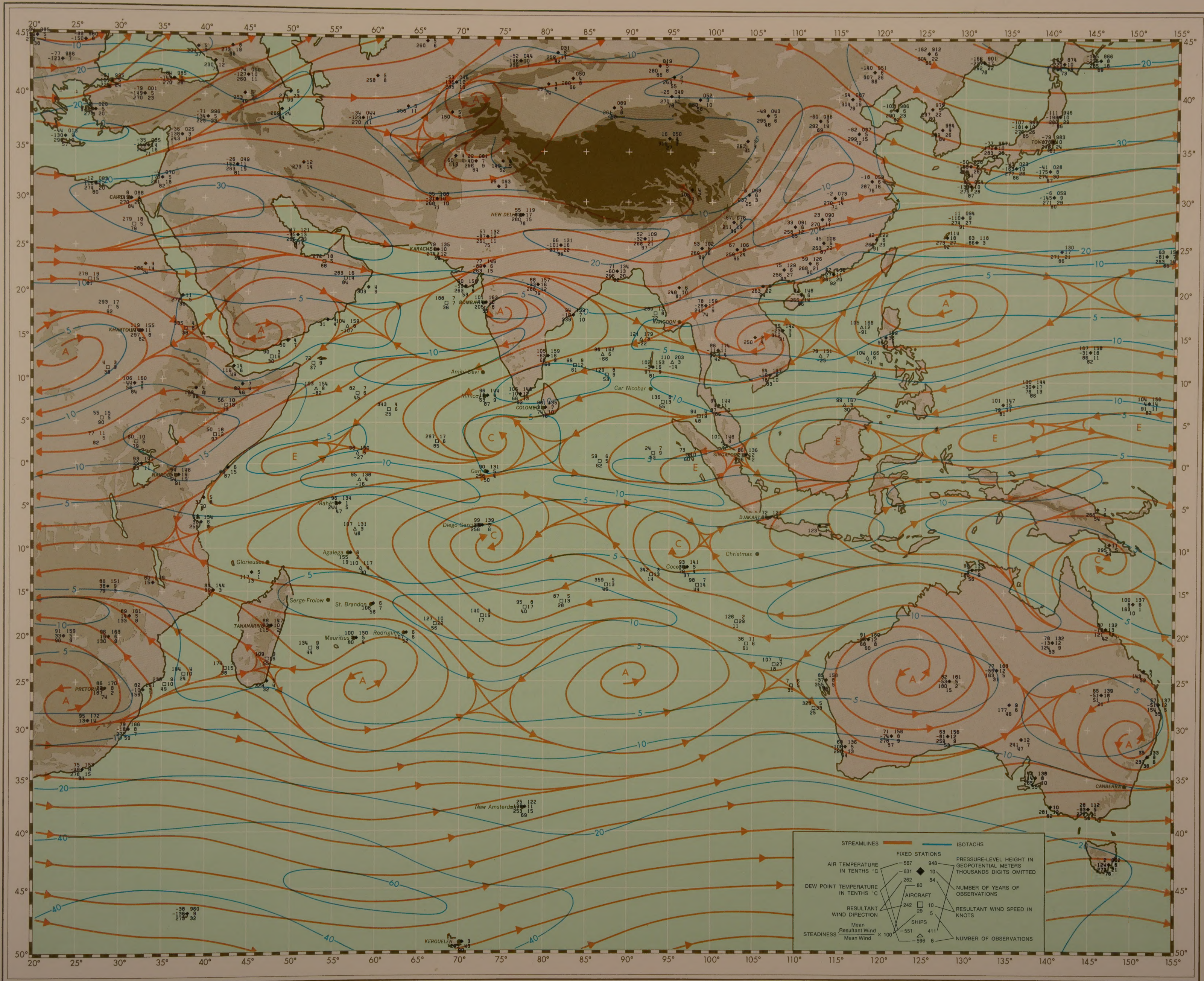




# MARCH 850 mb Chart 22

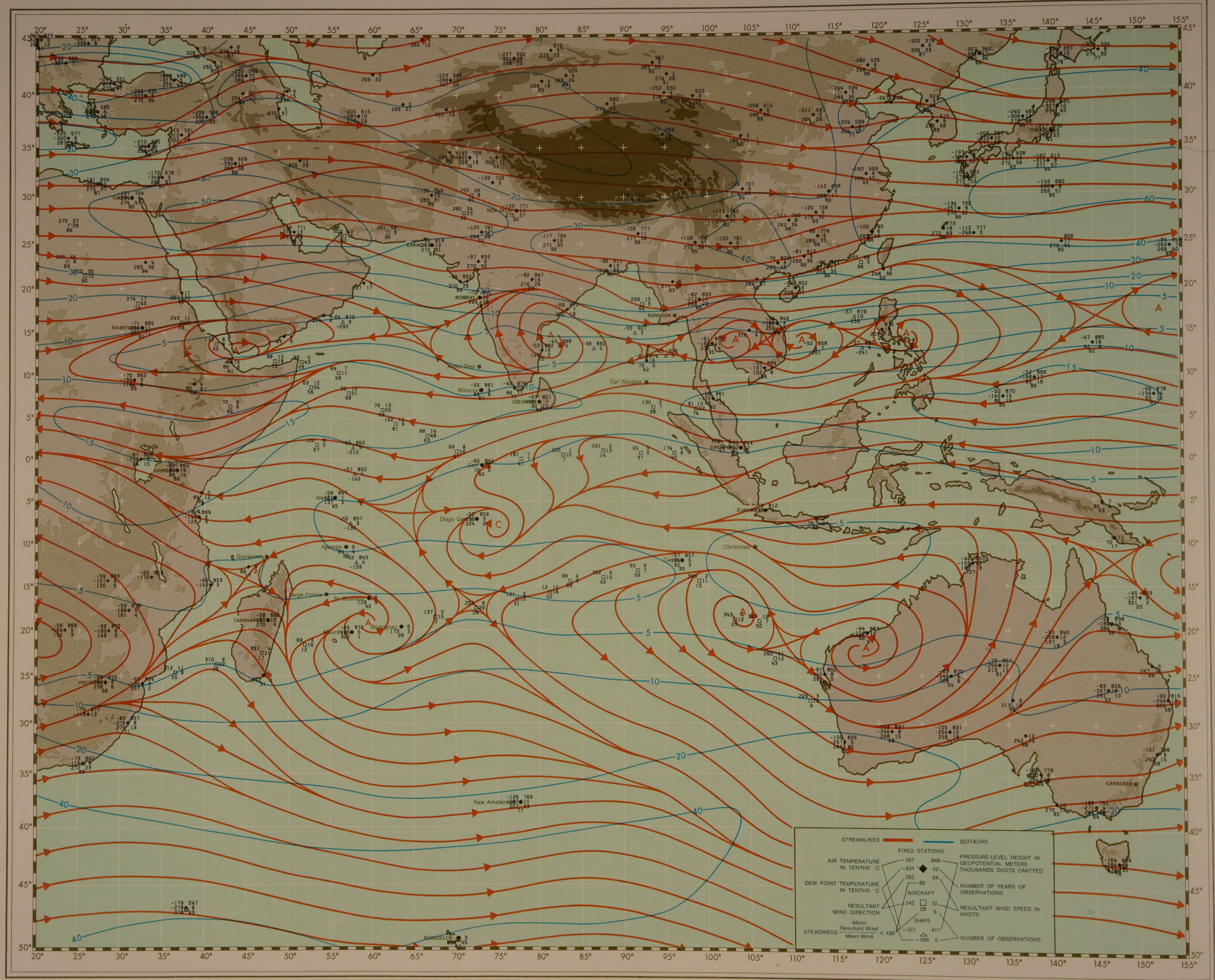






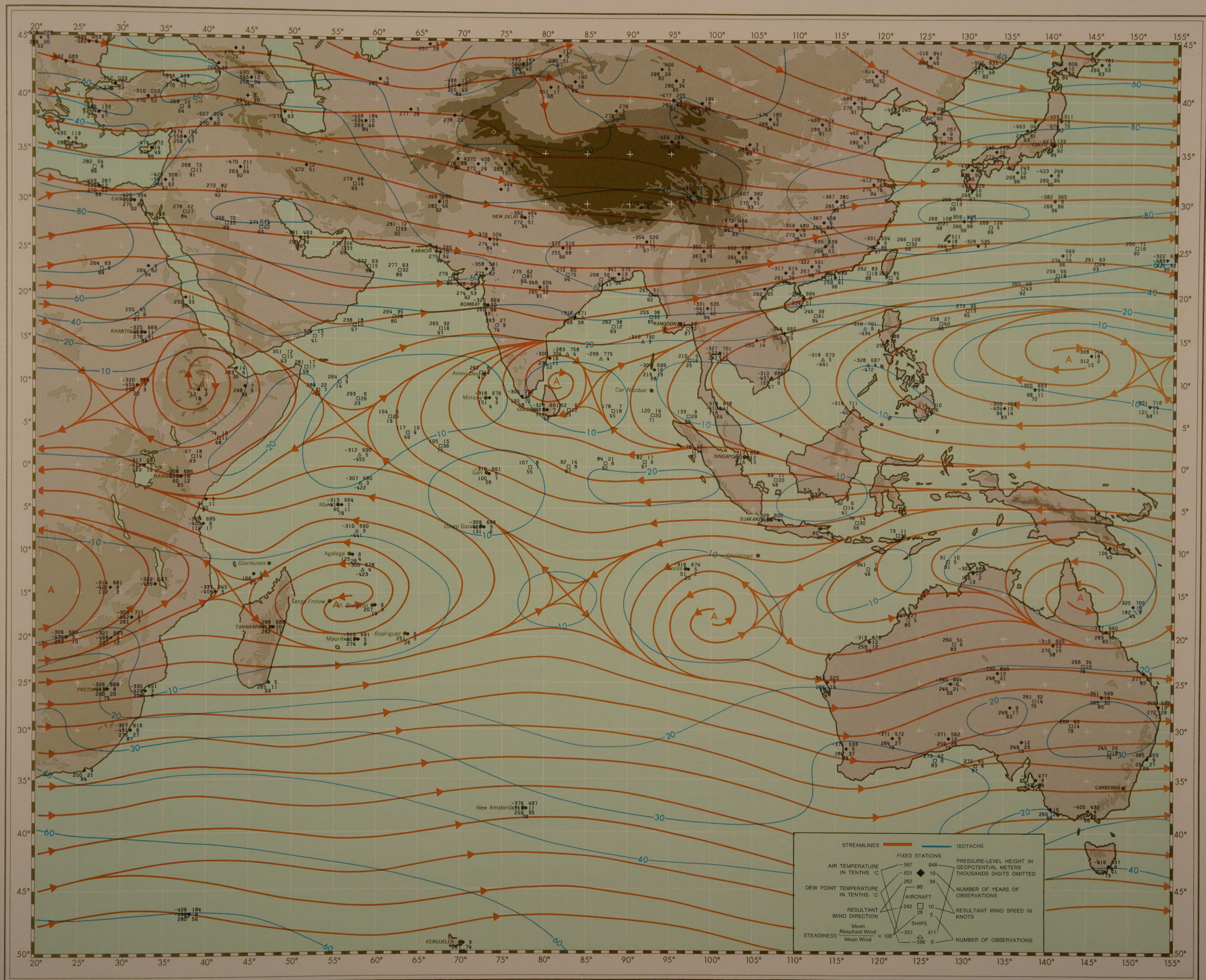


# MARCH 500 mb Chart 24



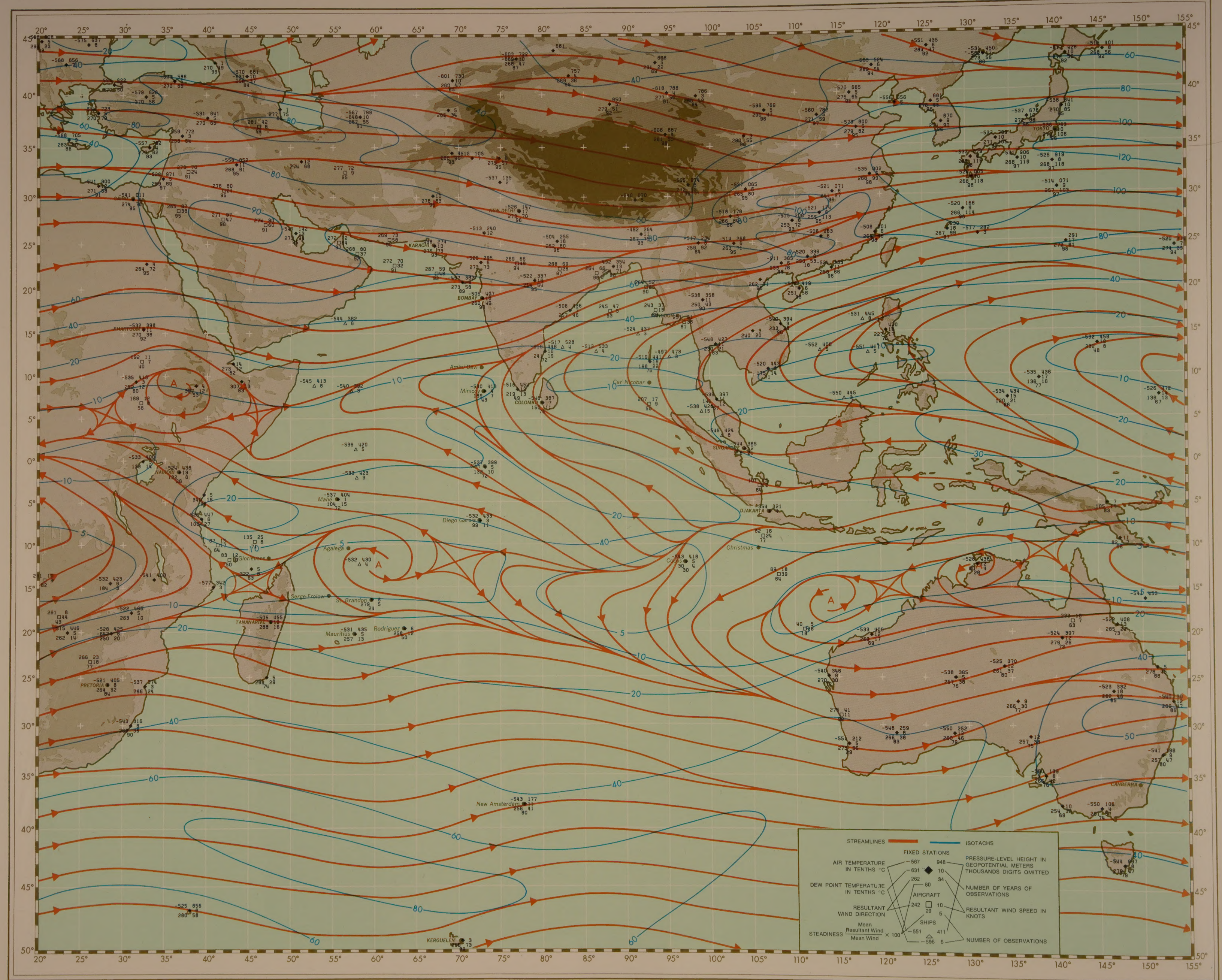


# MARCH 300 mb Chart 25

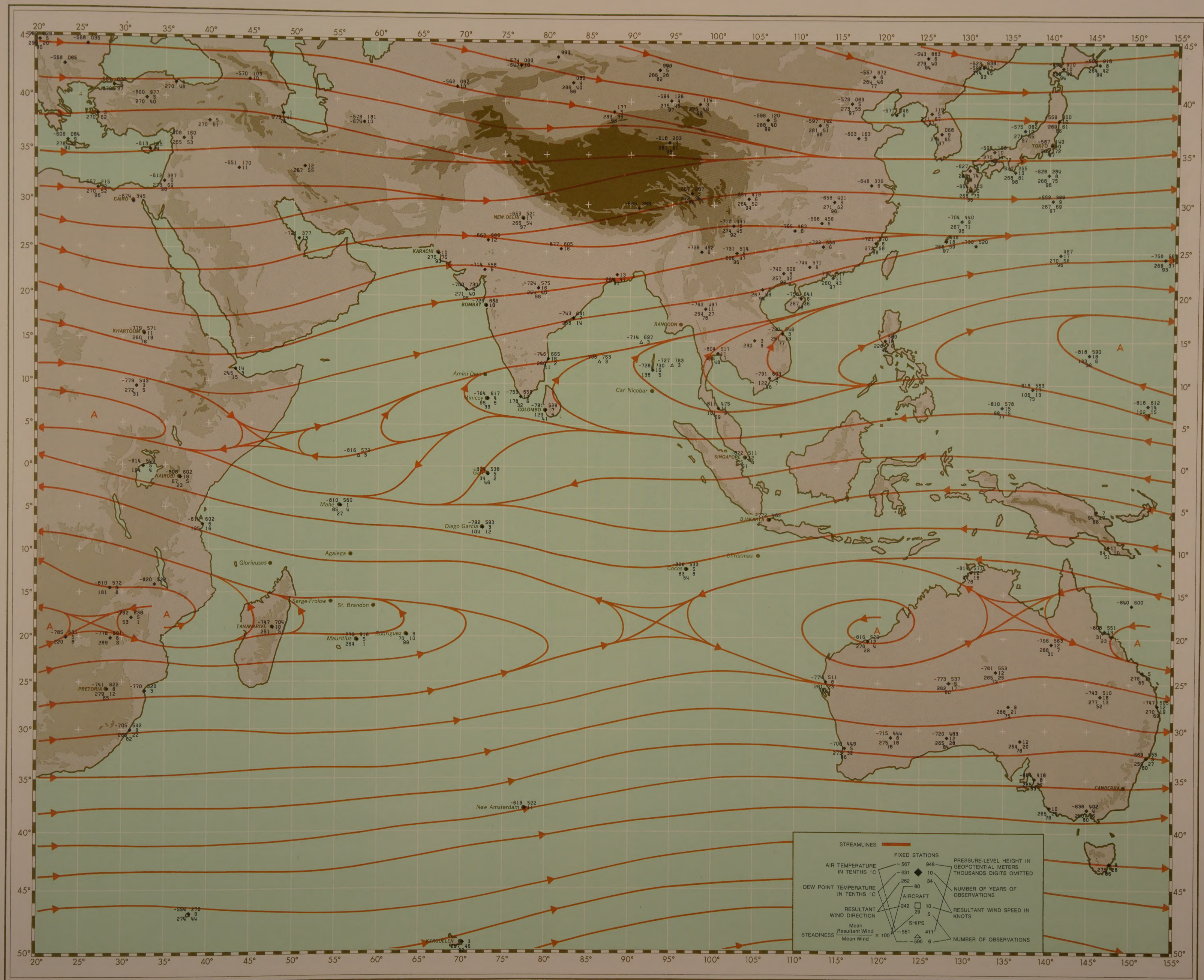




# MARCH 200 mb Chart 26

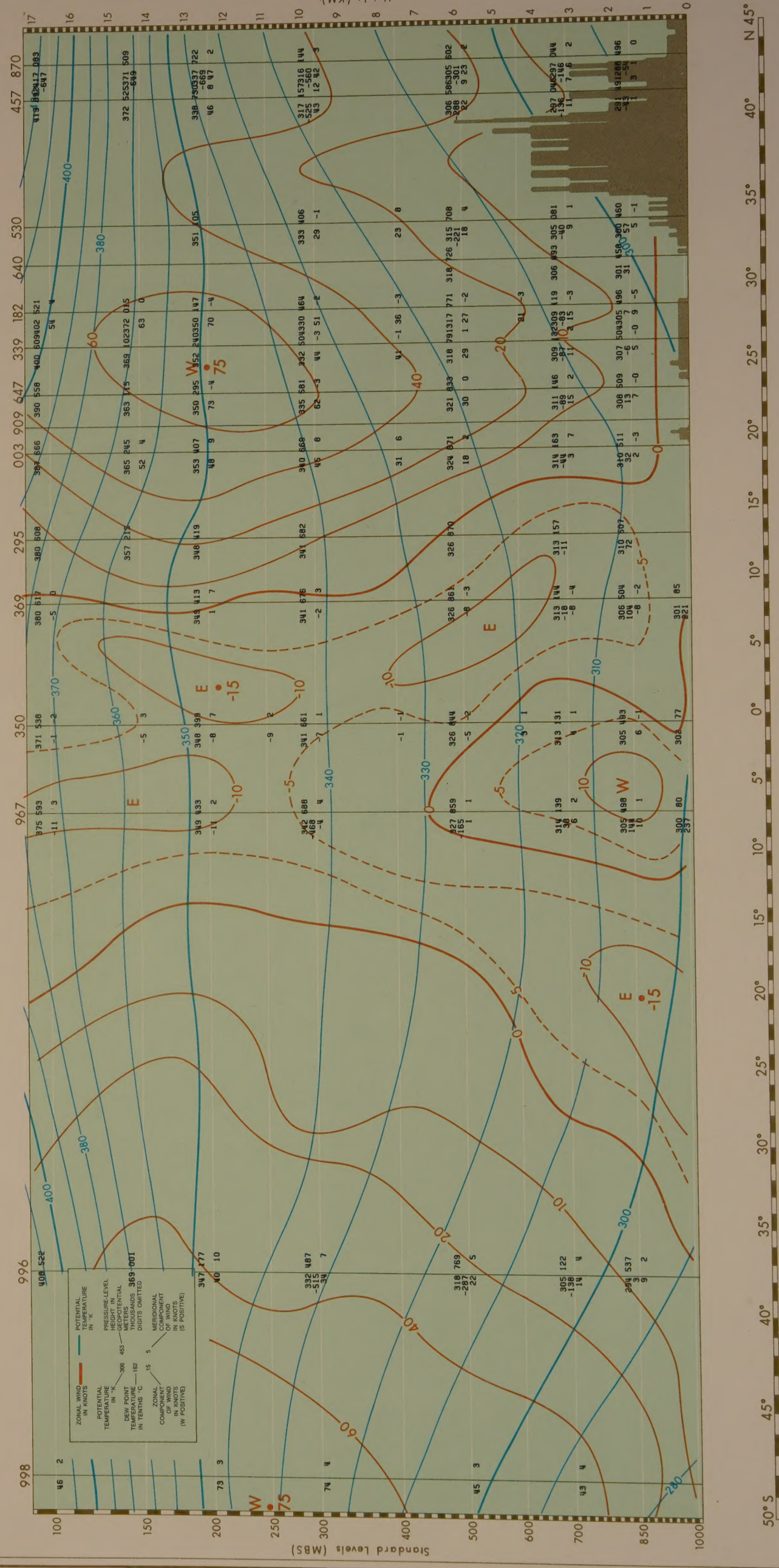
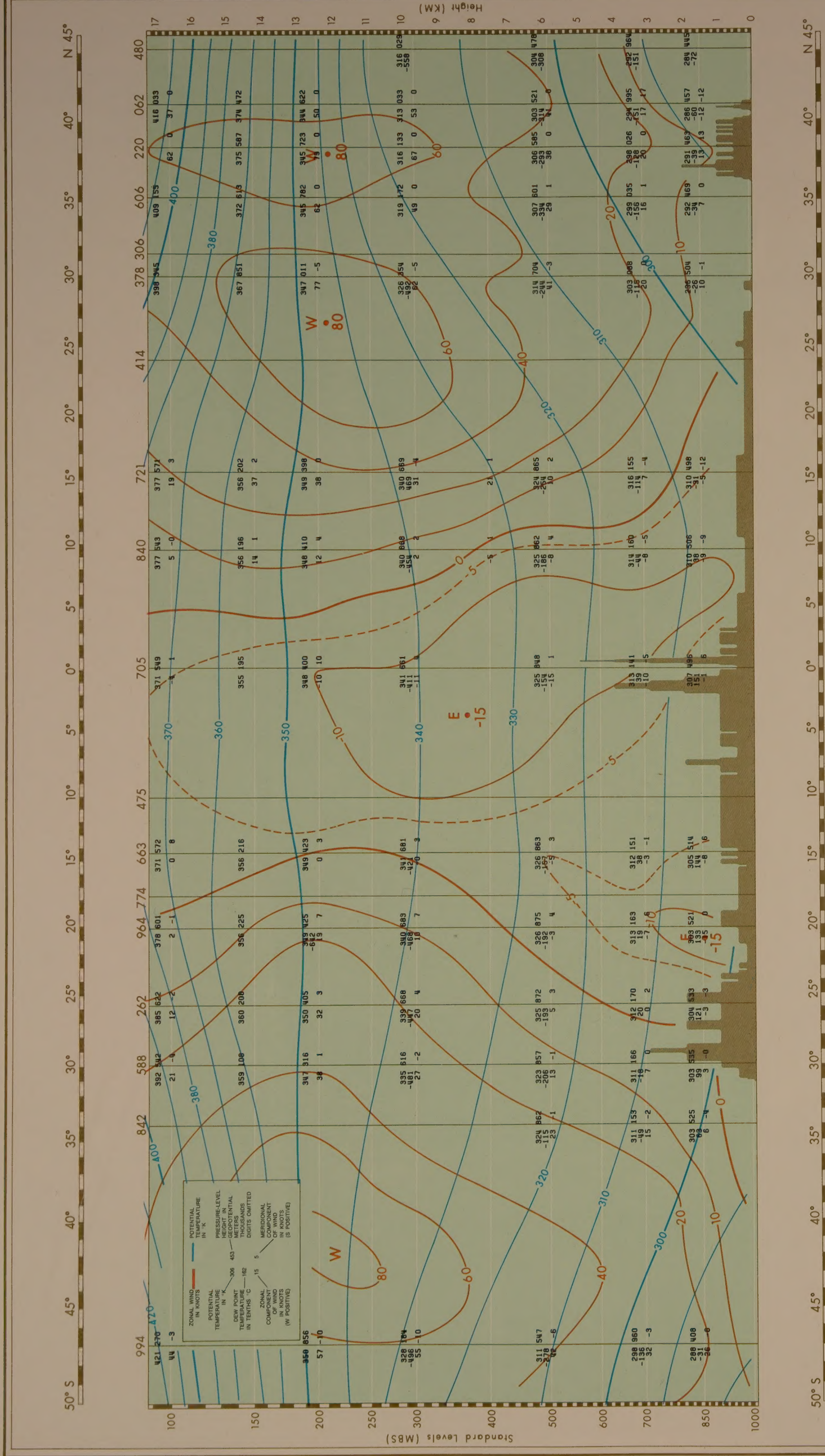




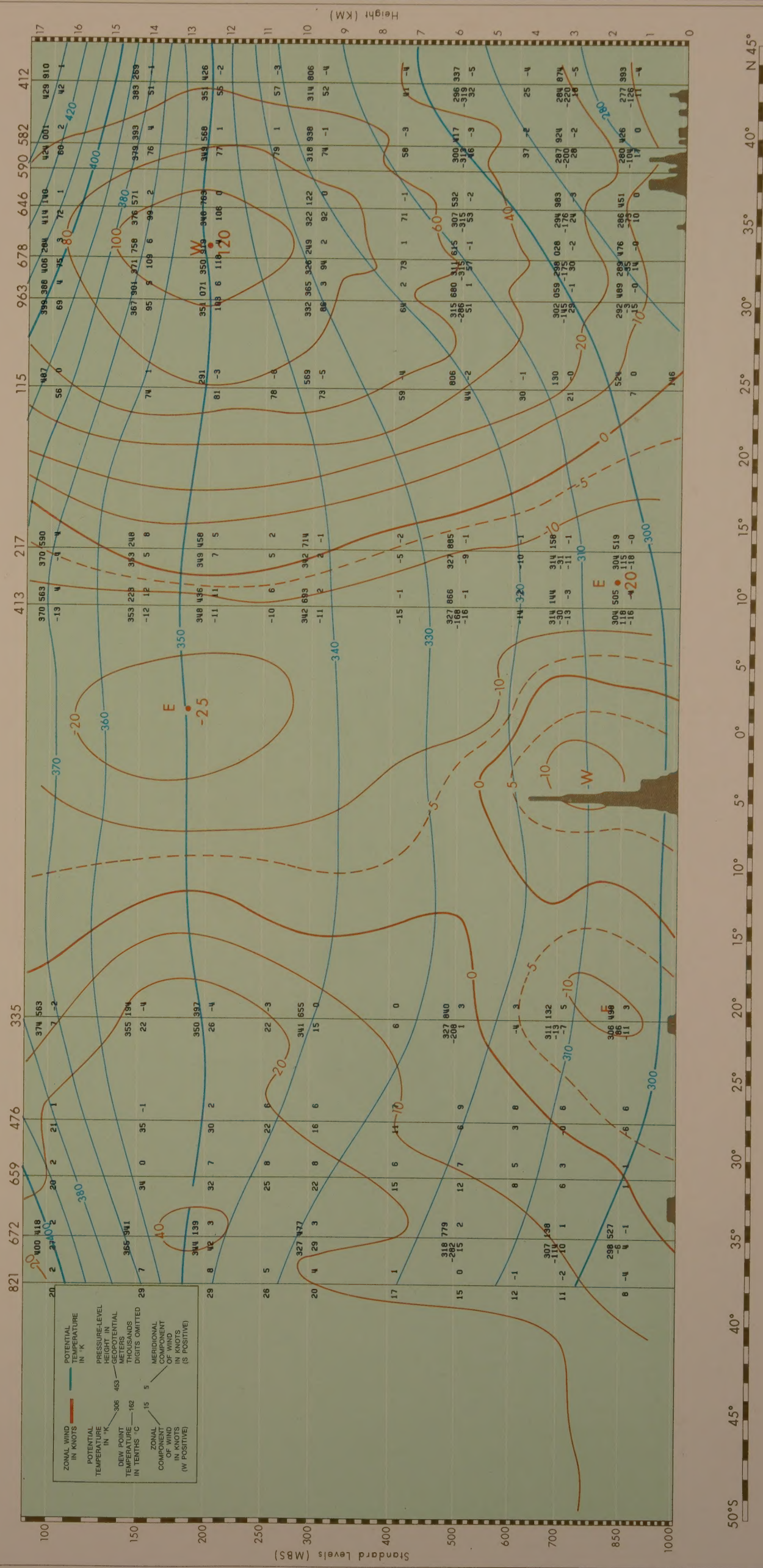
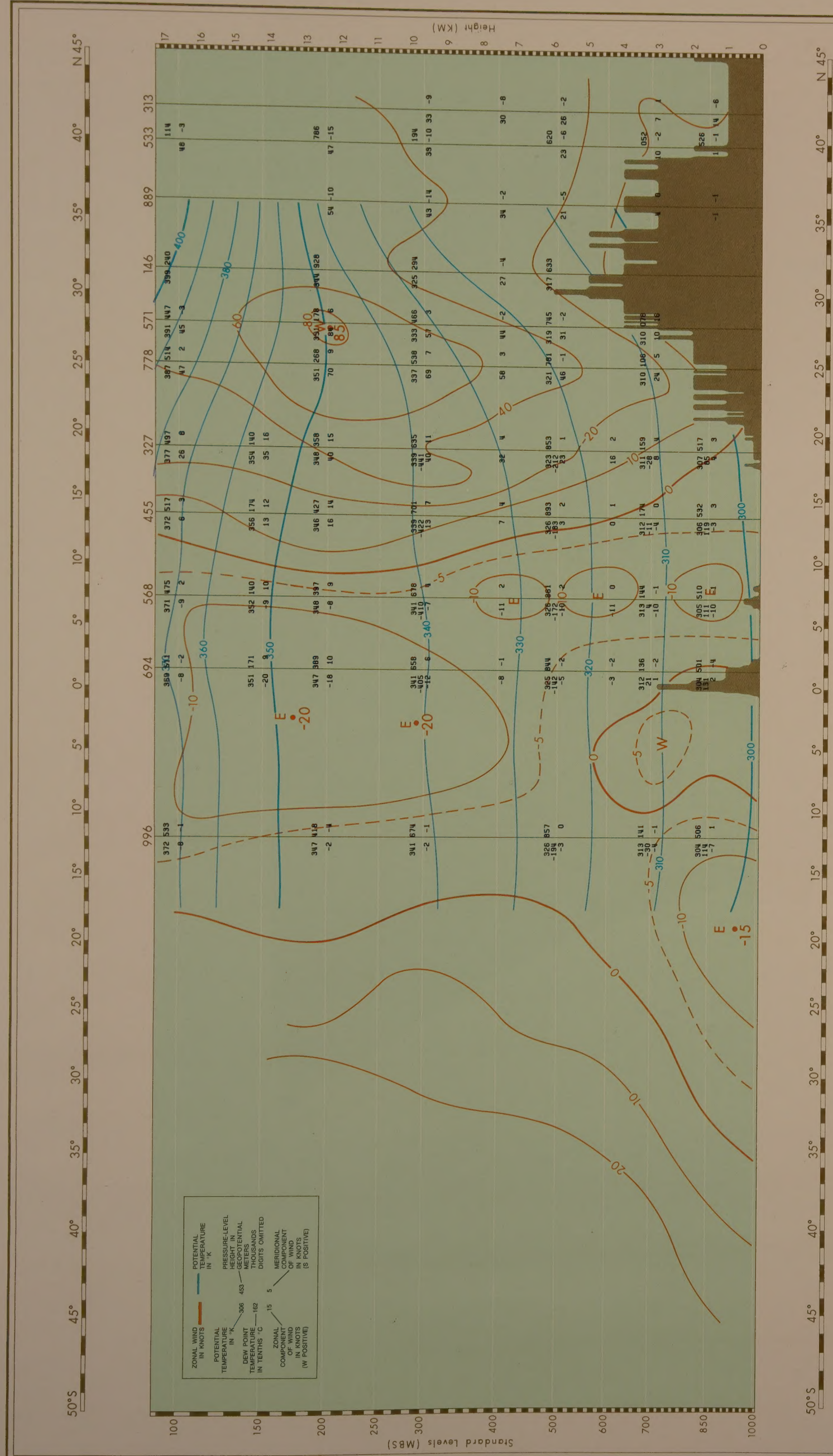




**MARCH 30 E**

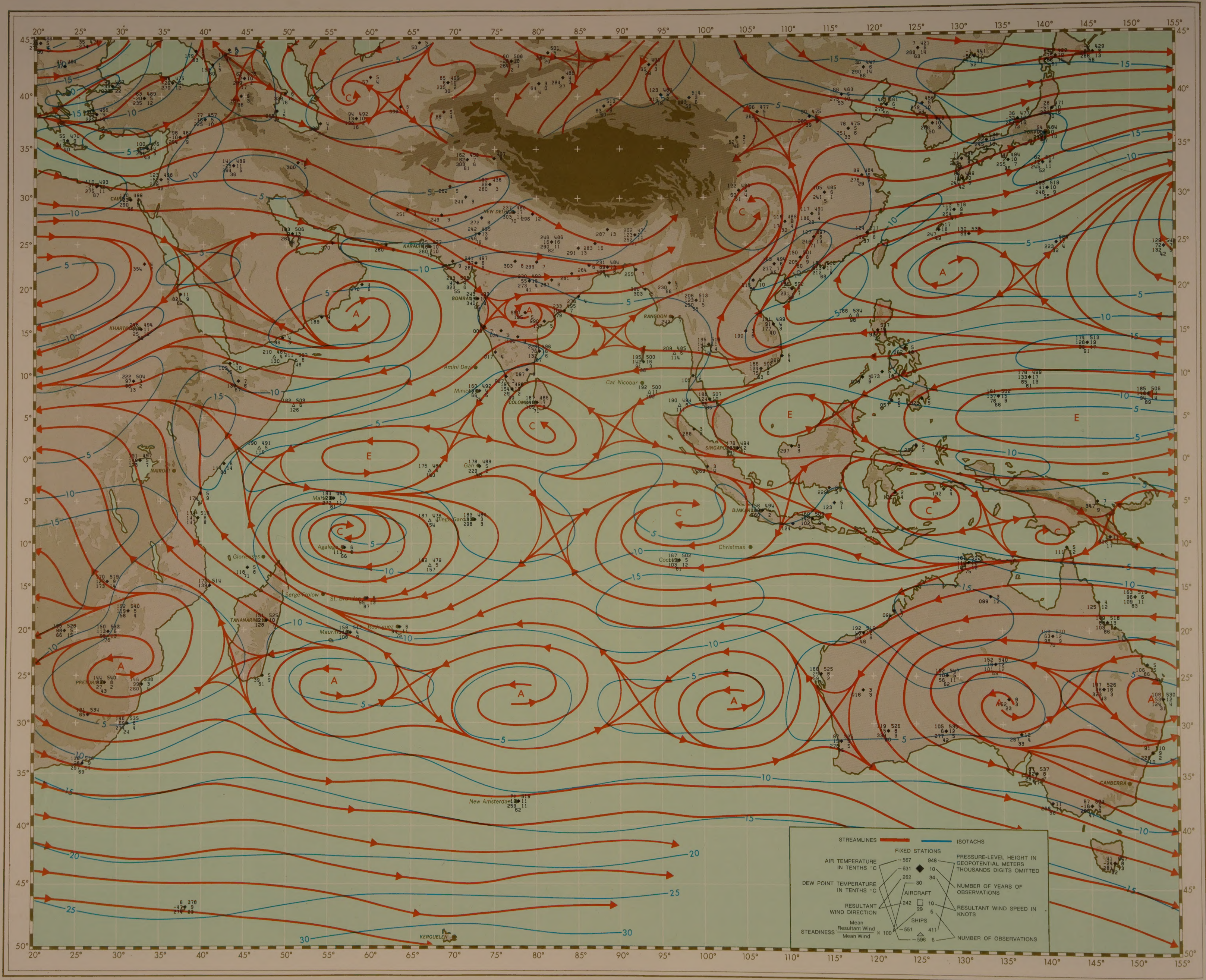




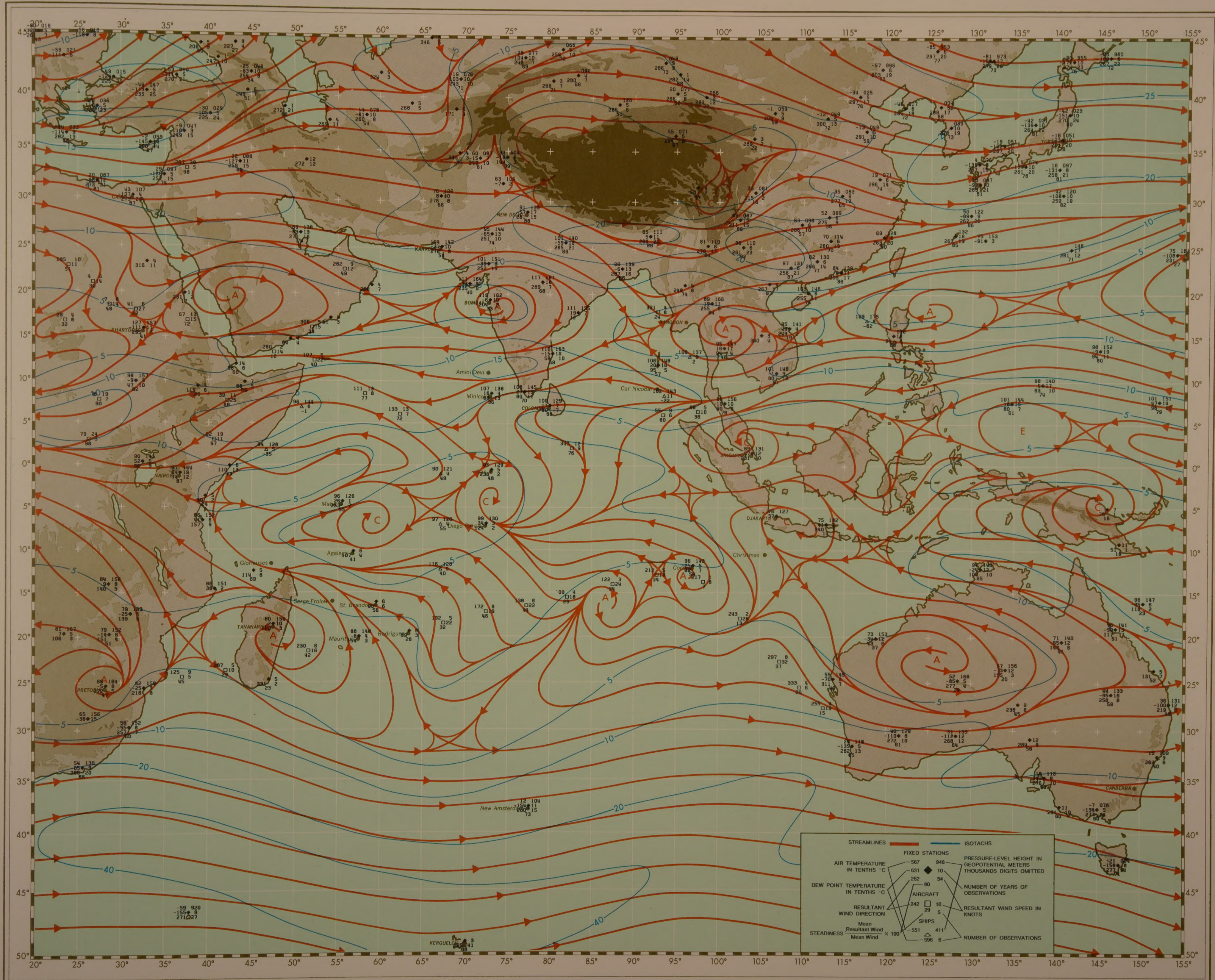




APRIL 850 mb Chart 32

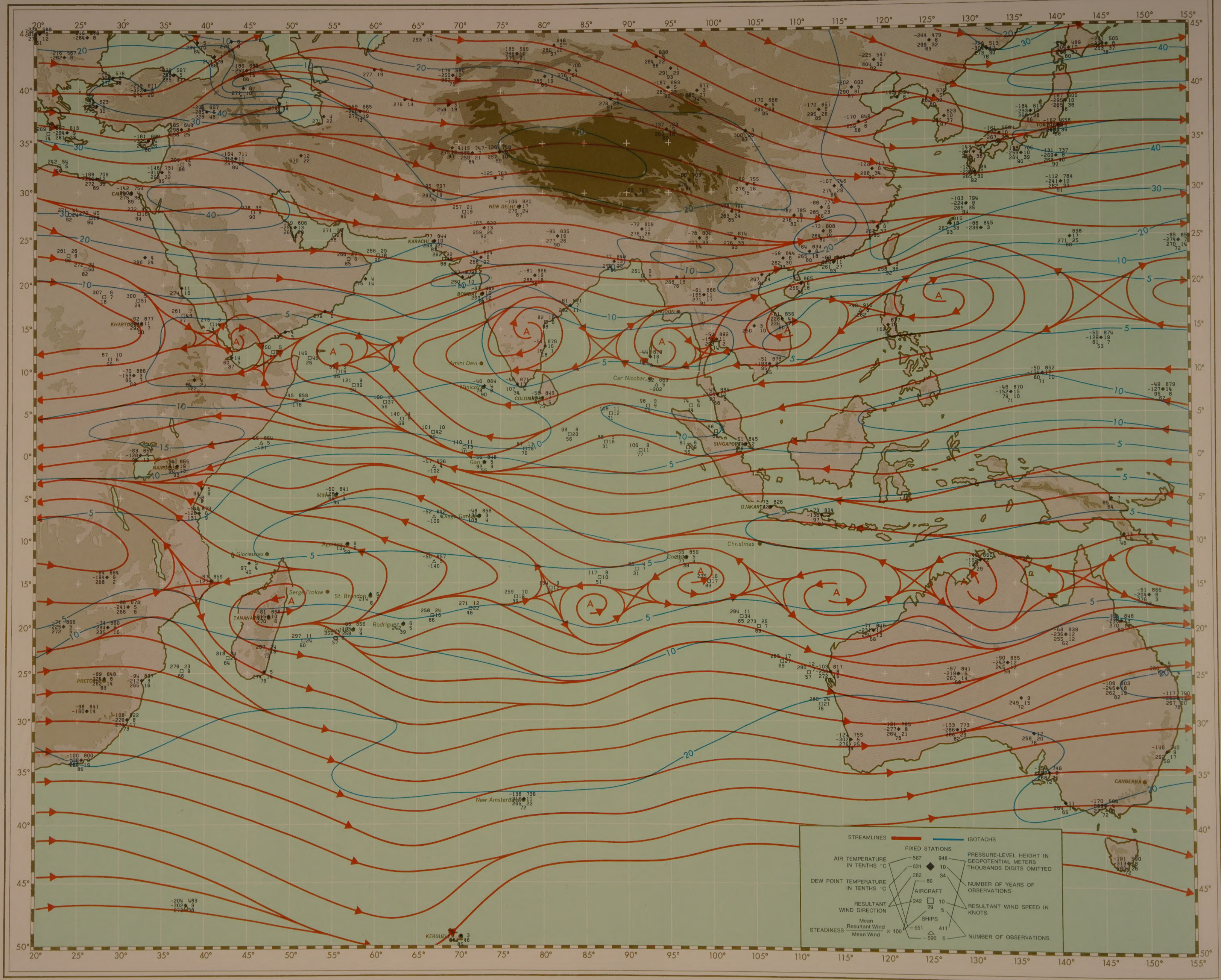








# APRIL 500 mb Chart 34

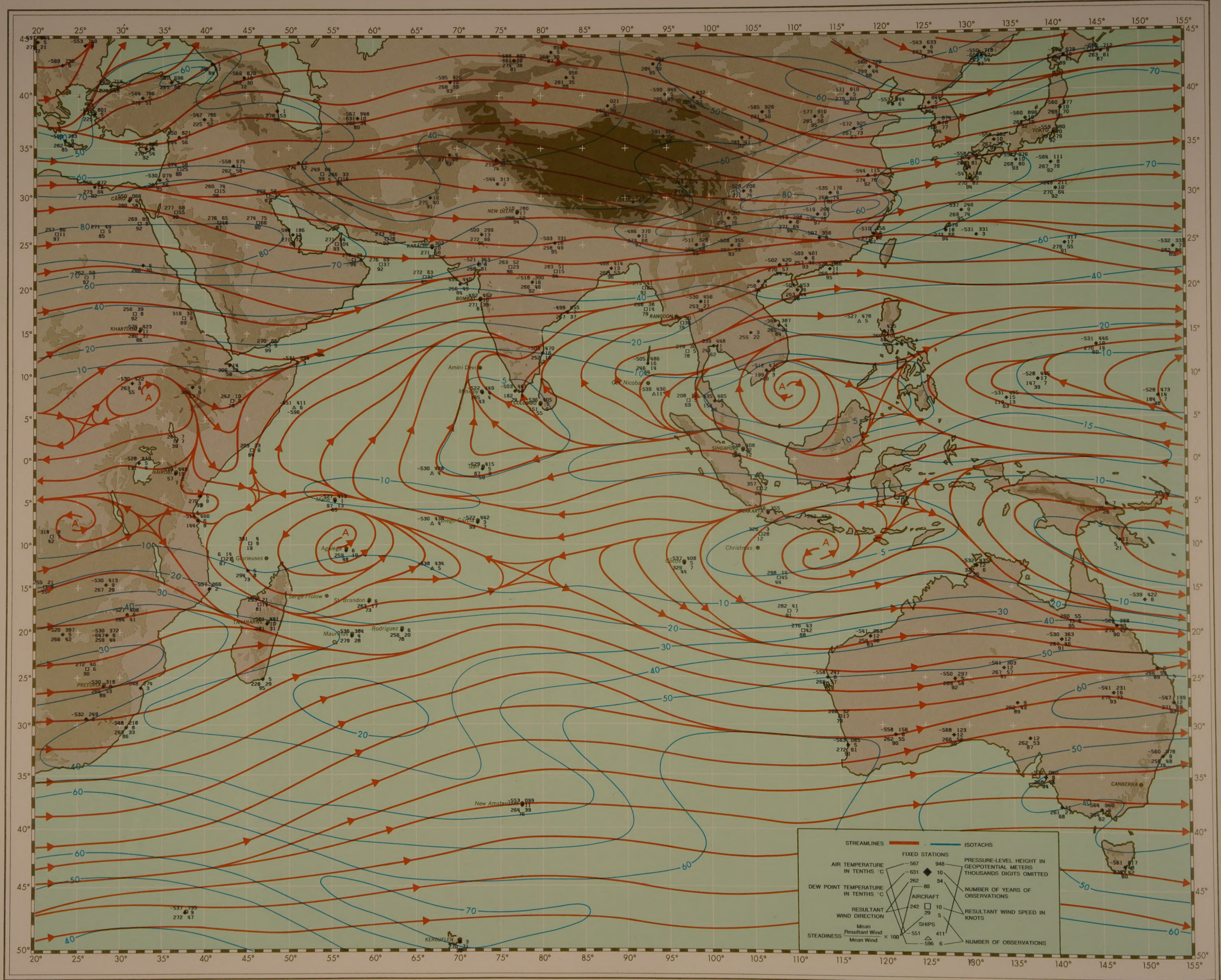




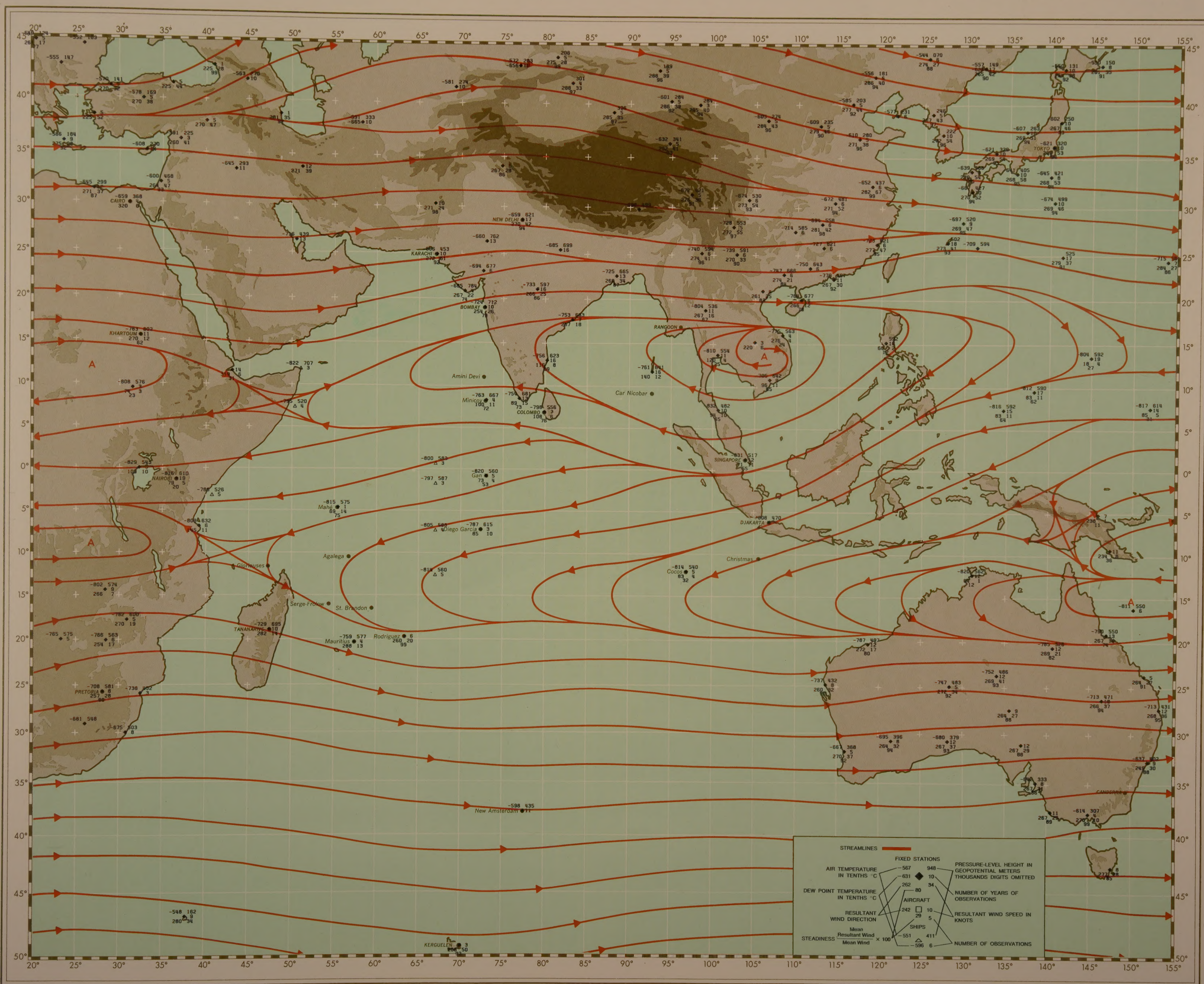




# APRIL 200 mb Chart 36

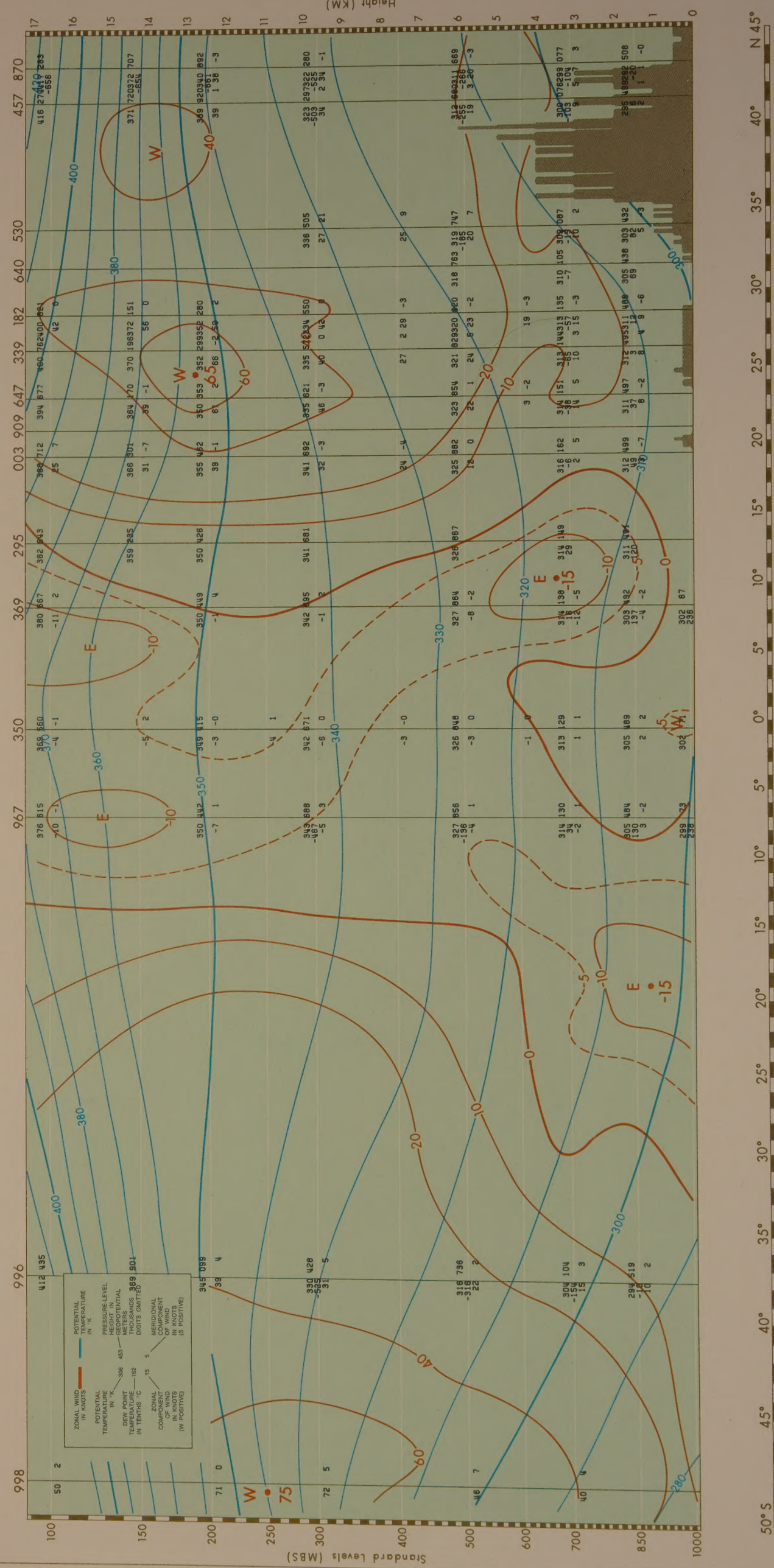
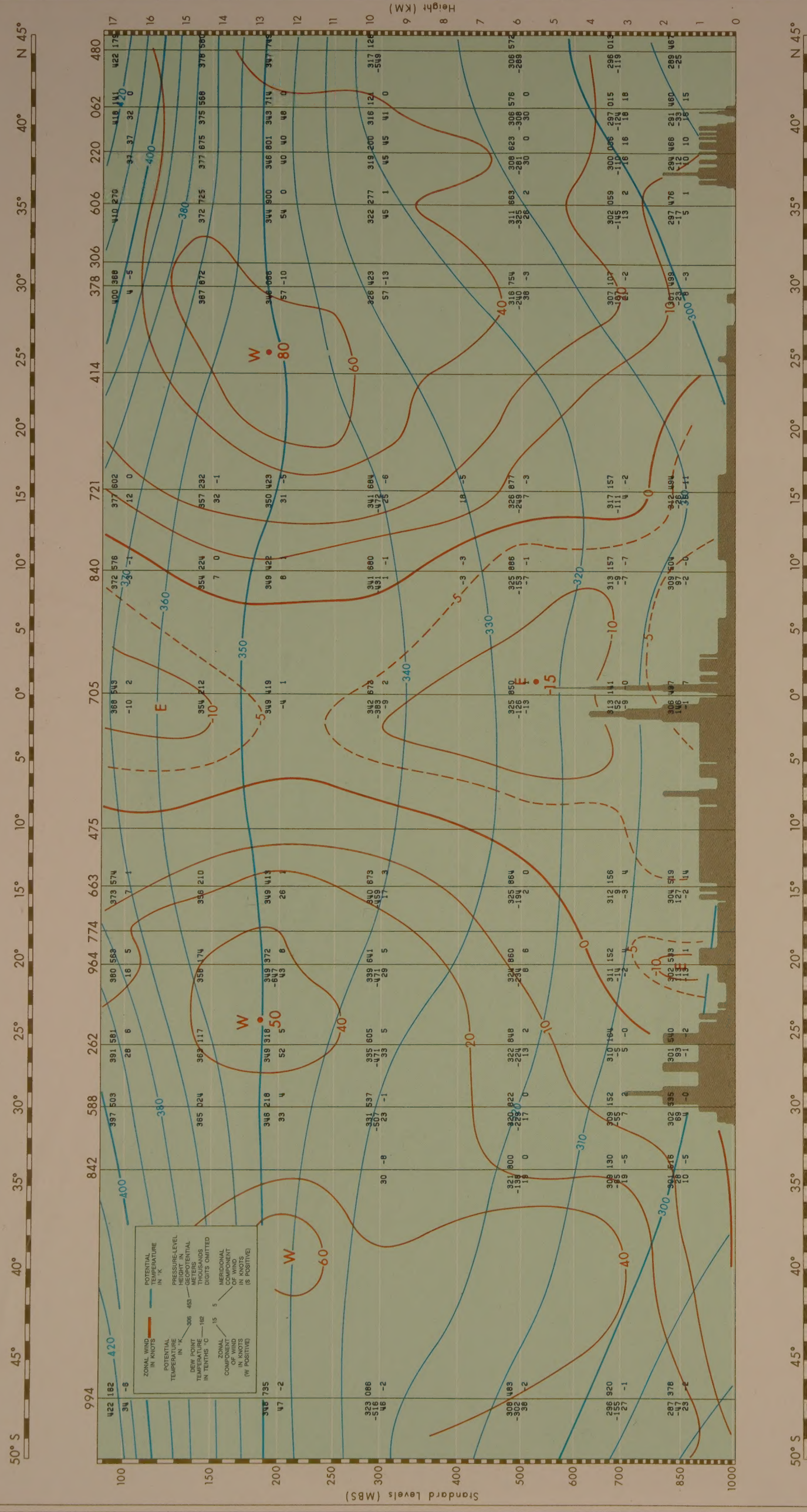




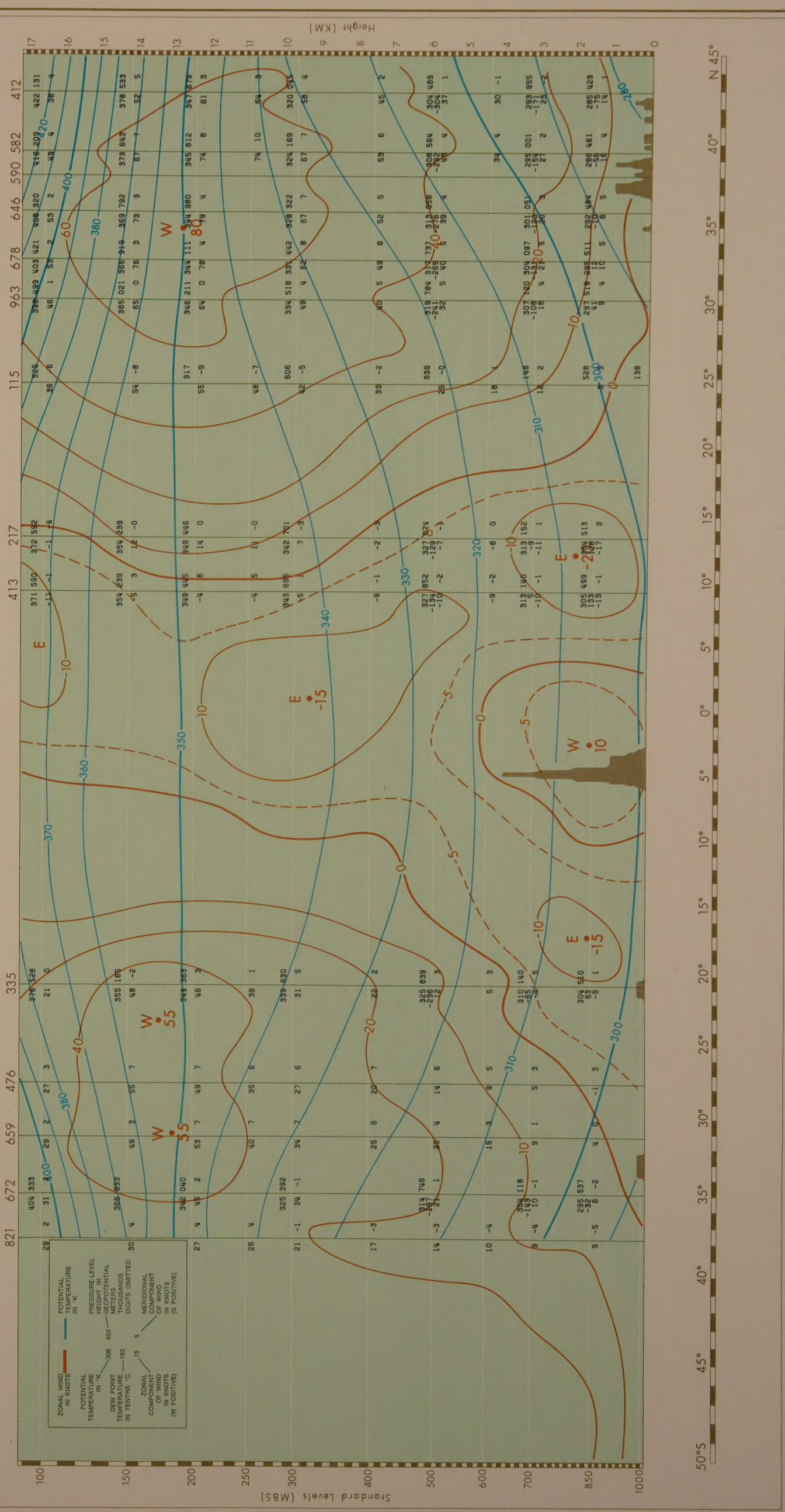
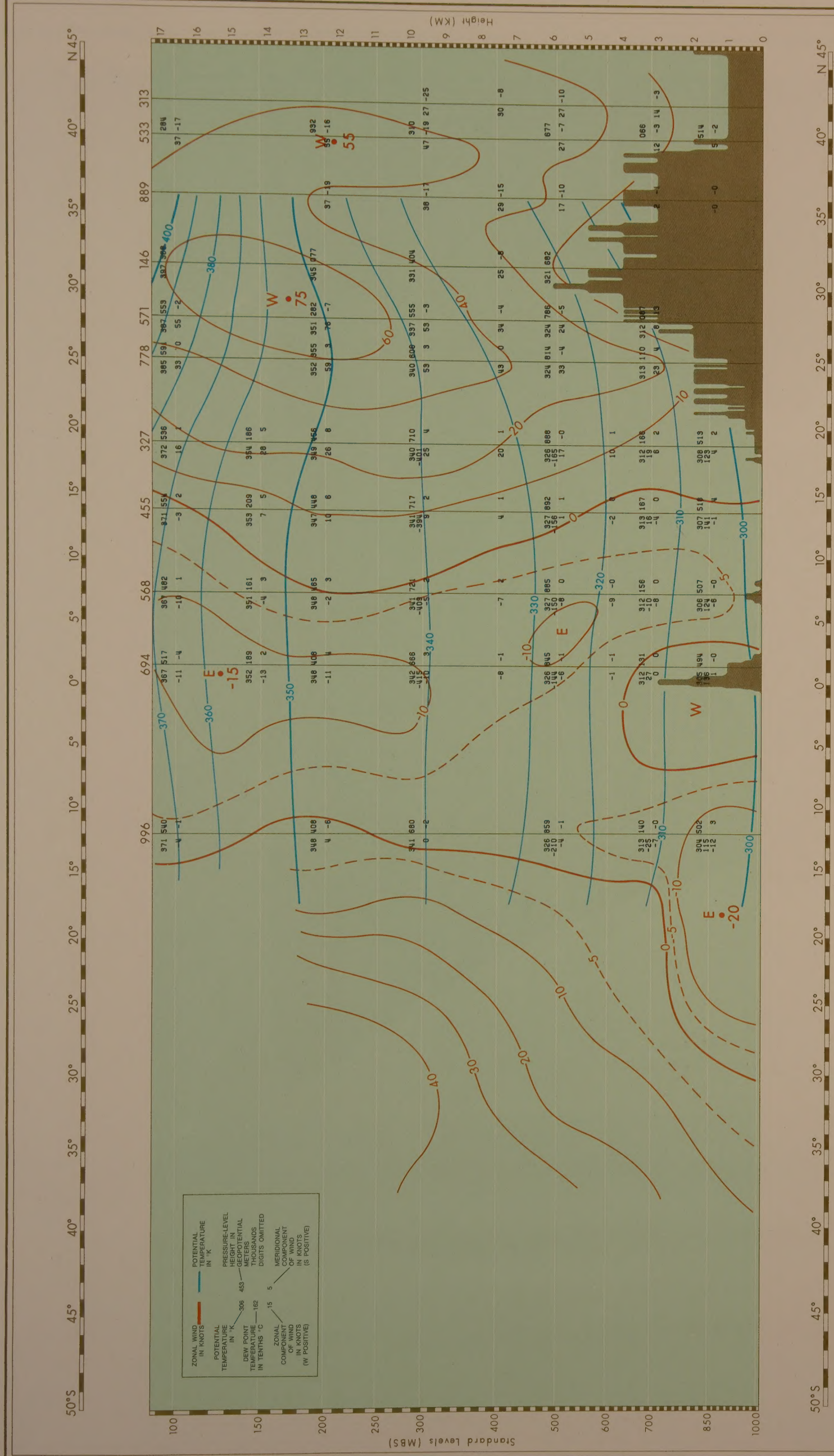




# APRIL 30 E Chart 38

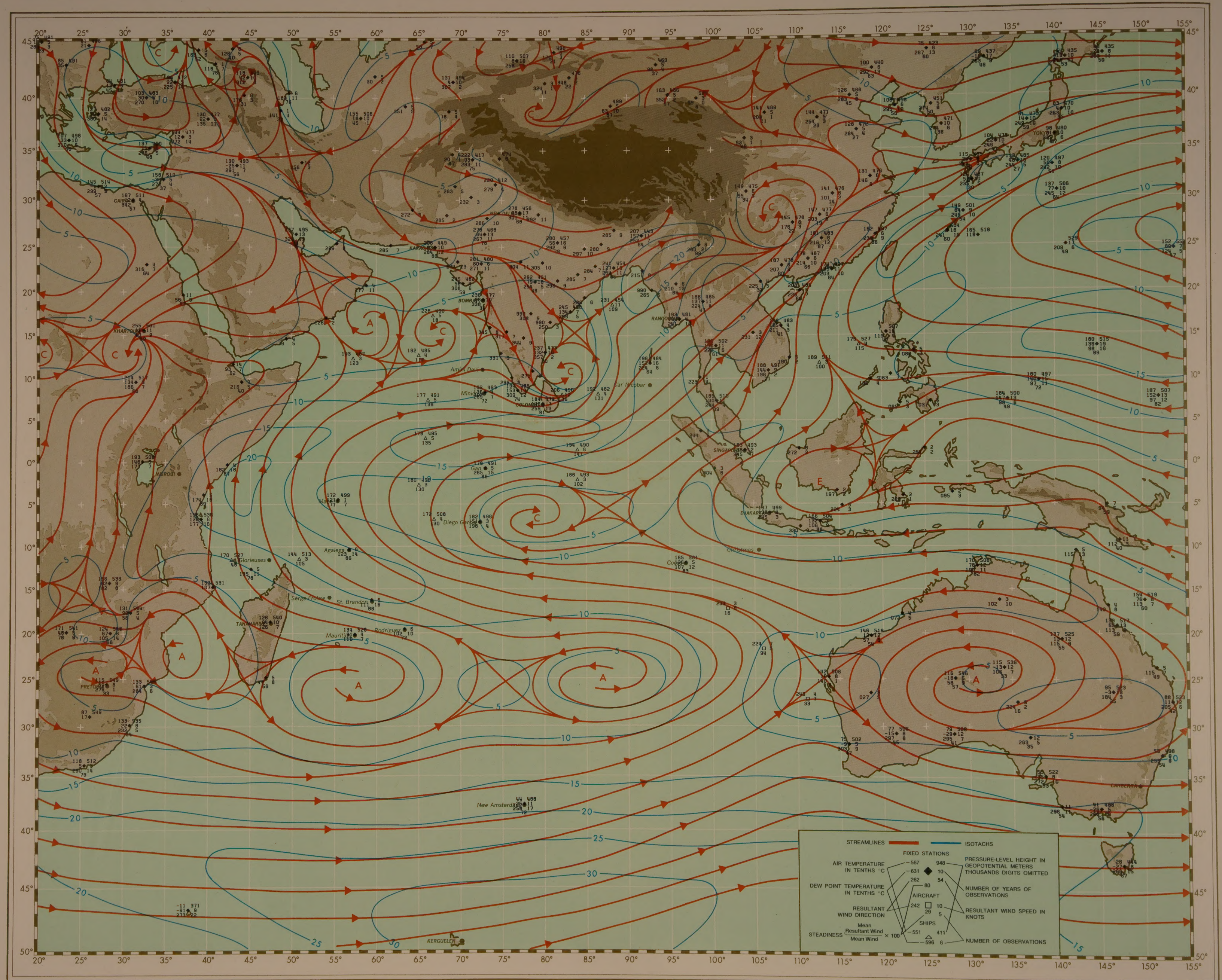




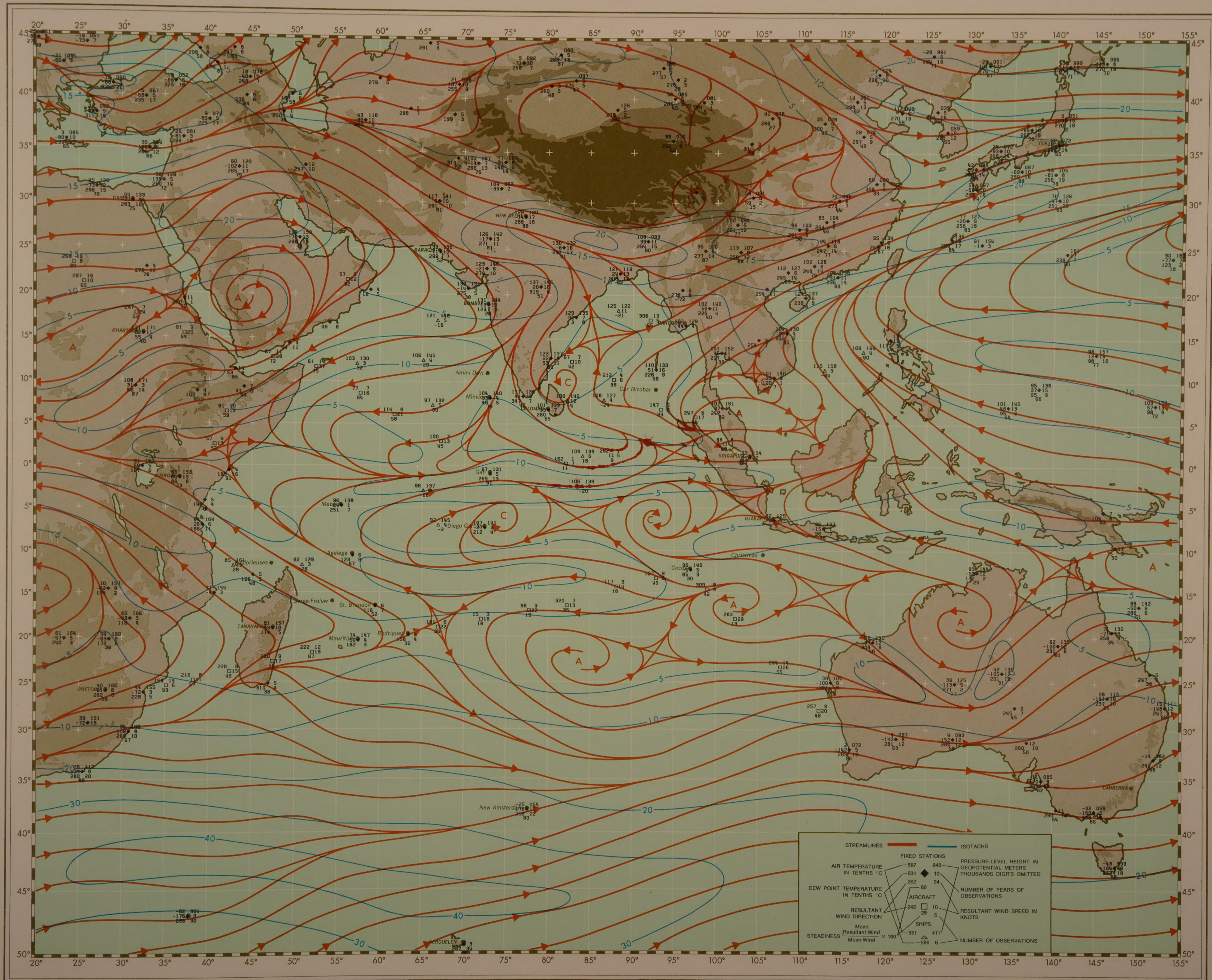




# MAY 850 mb Chart 42

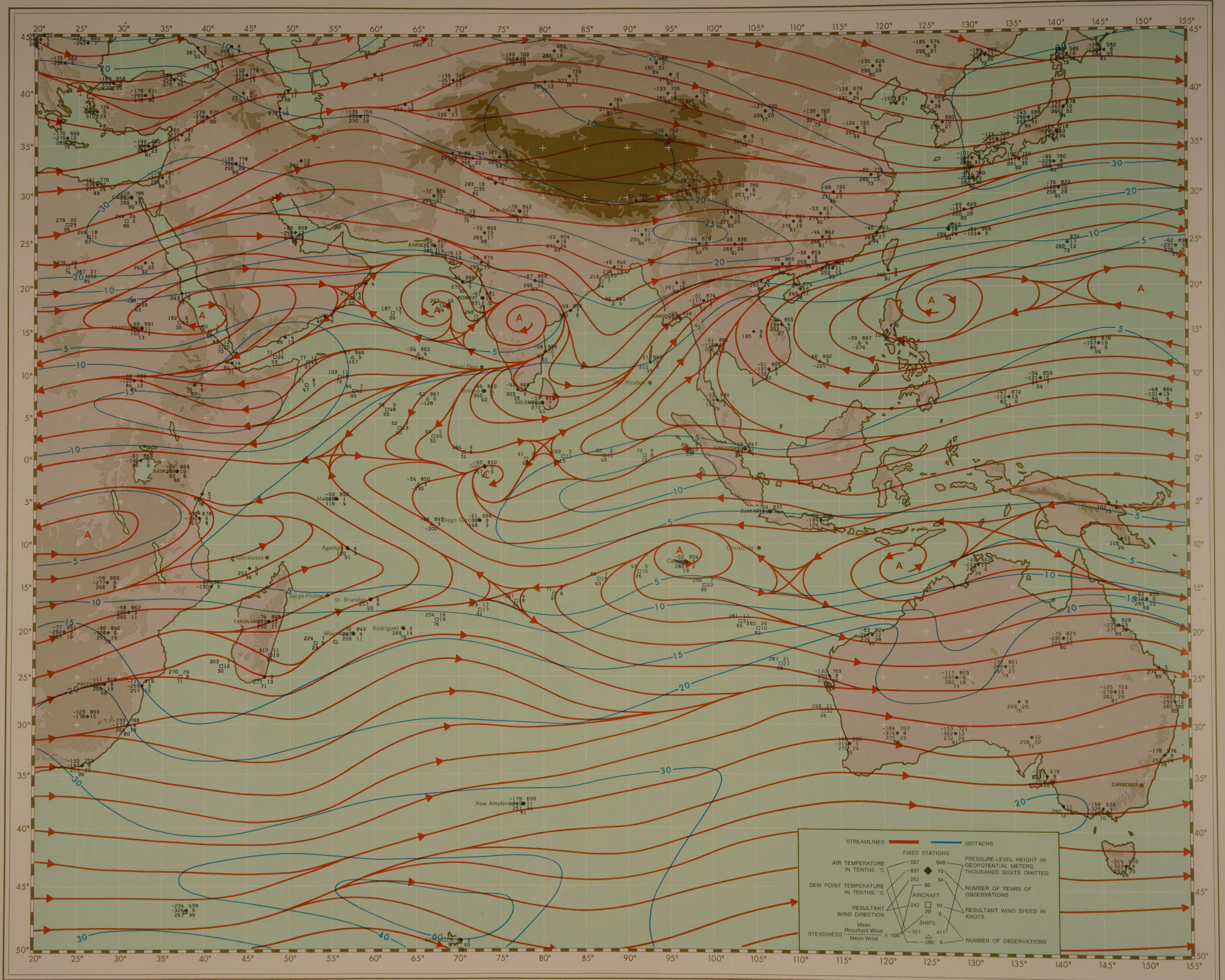








# MAY 500 mb Chart 44

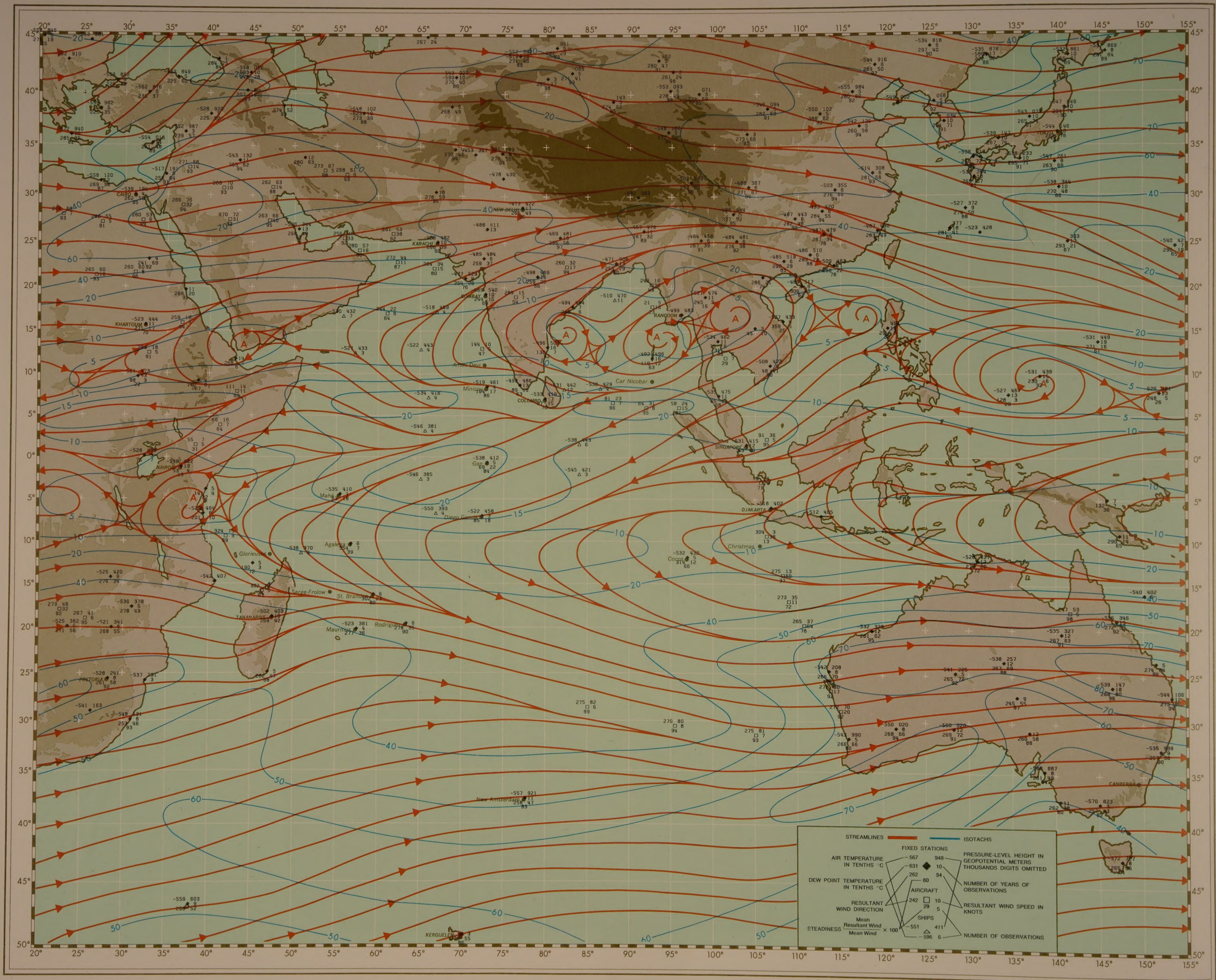




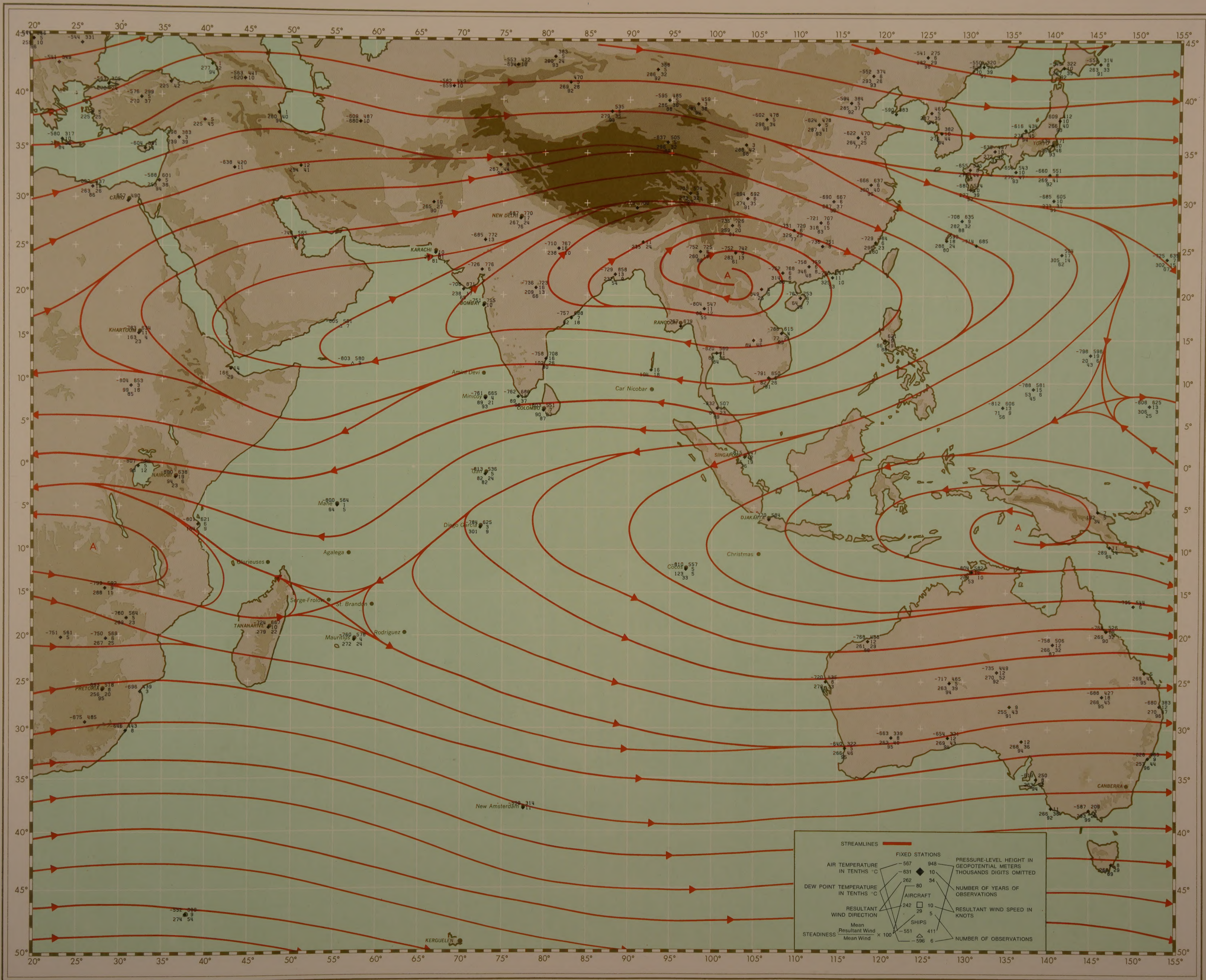




# MAY 200 mb Chart 46

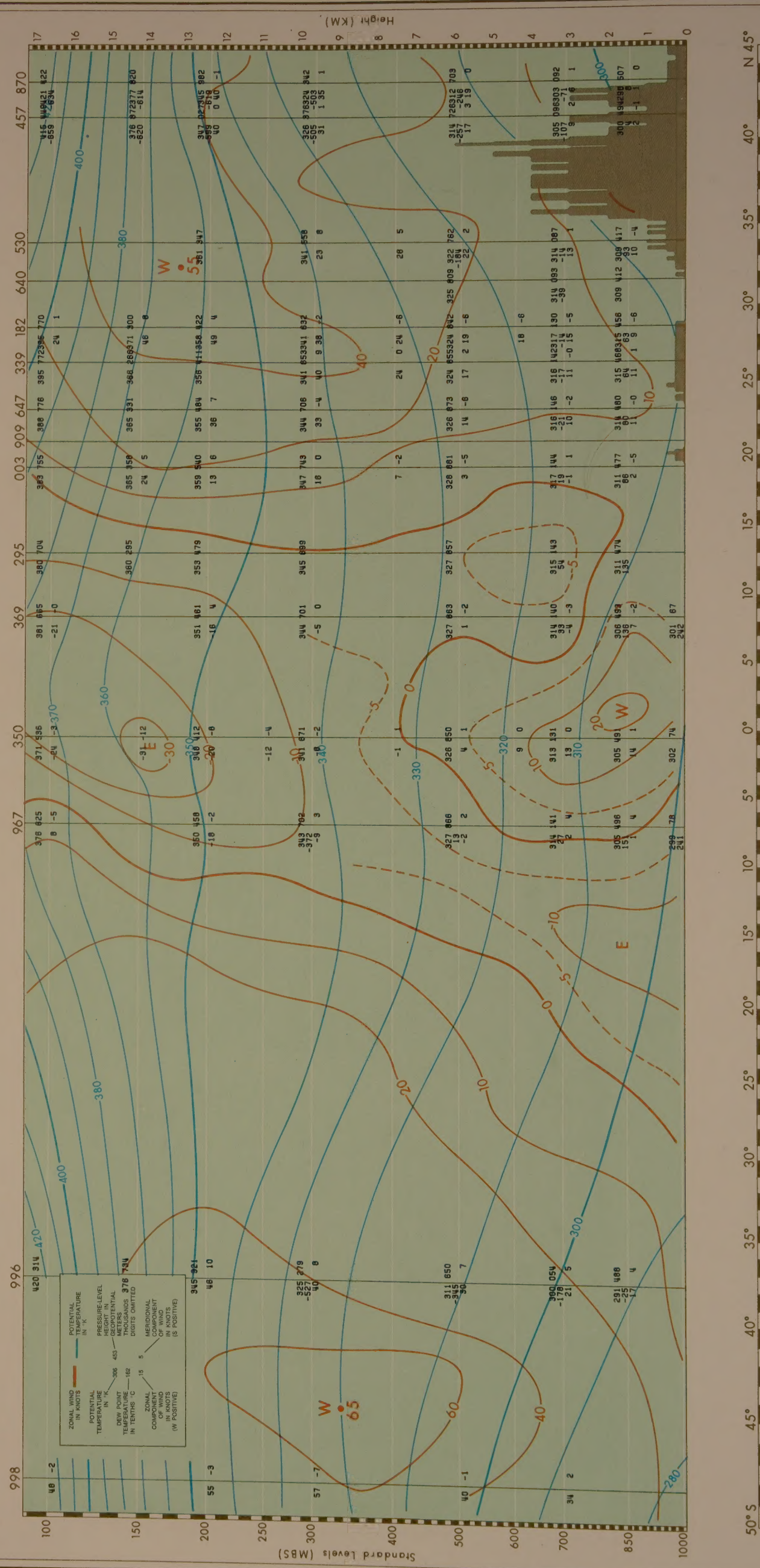
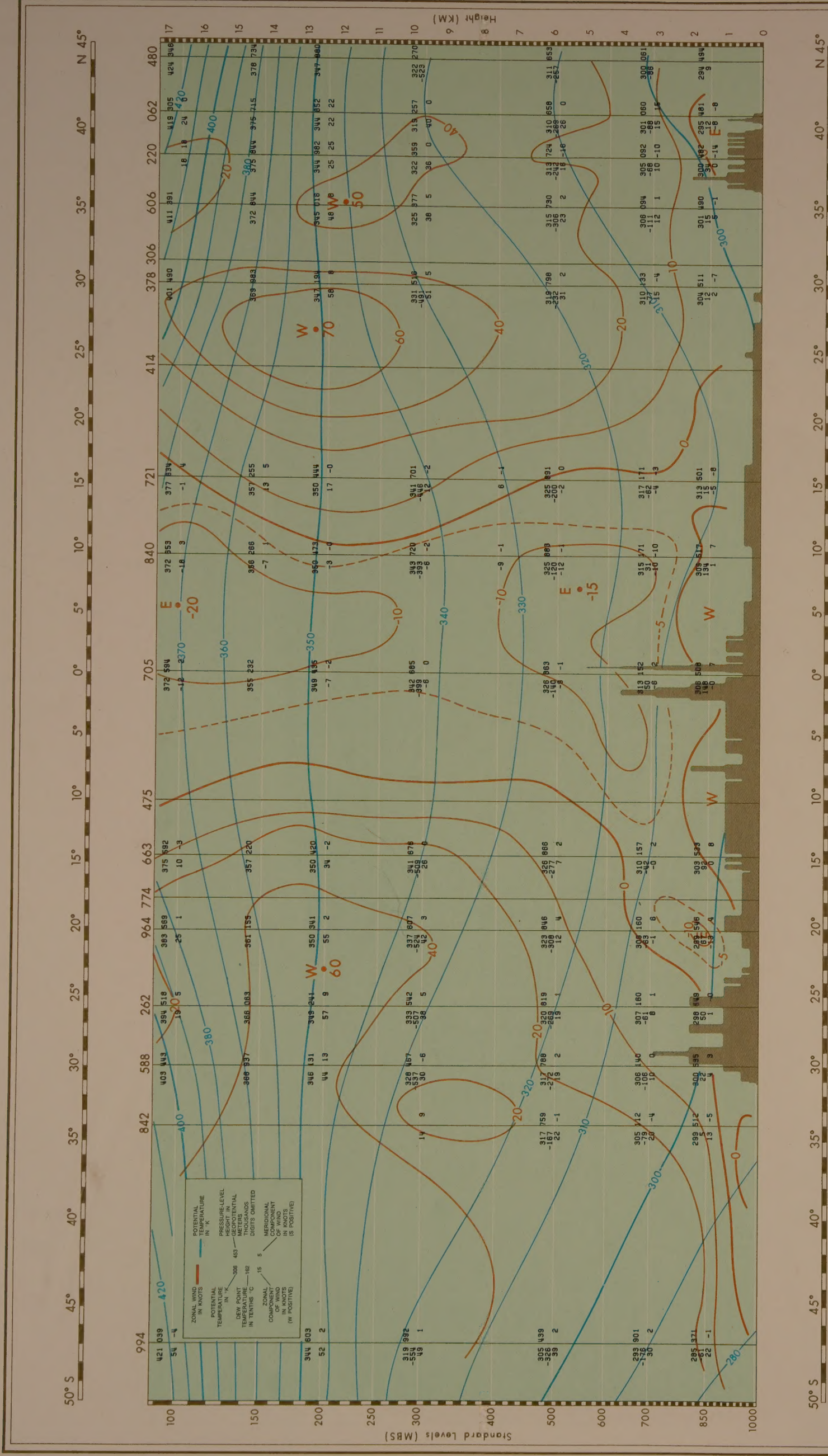






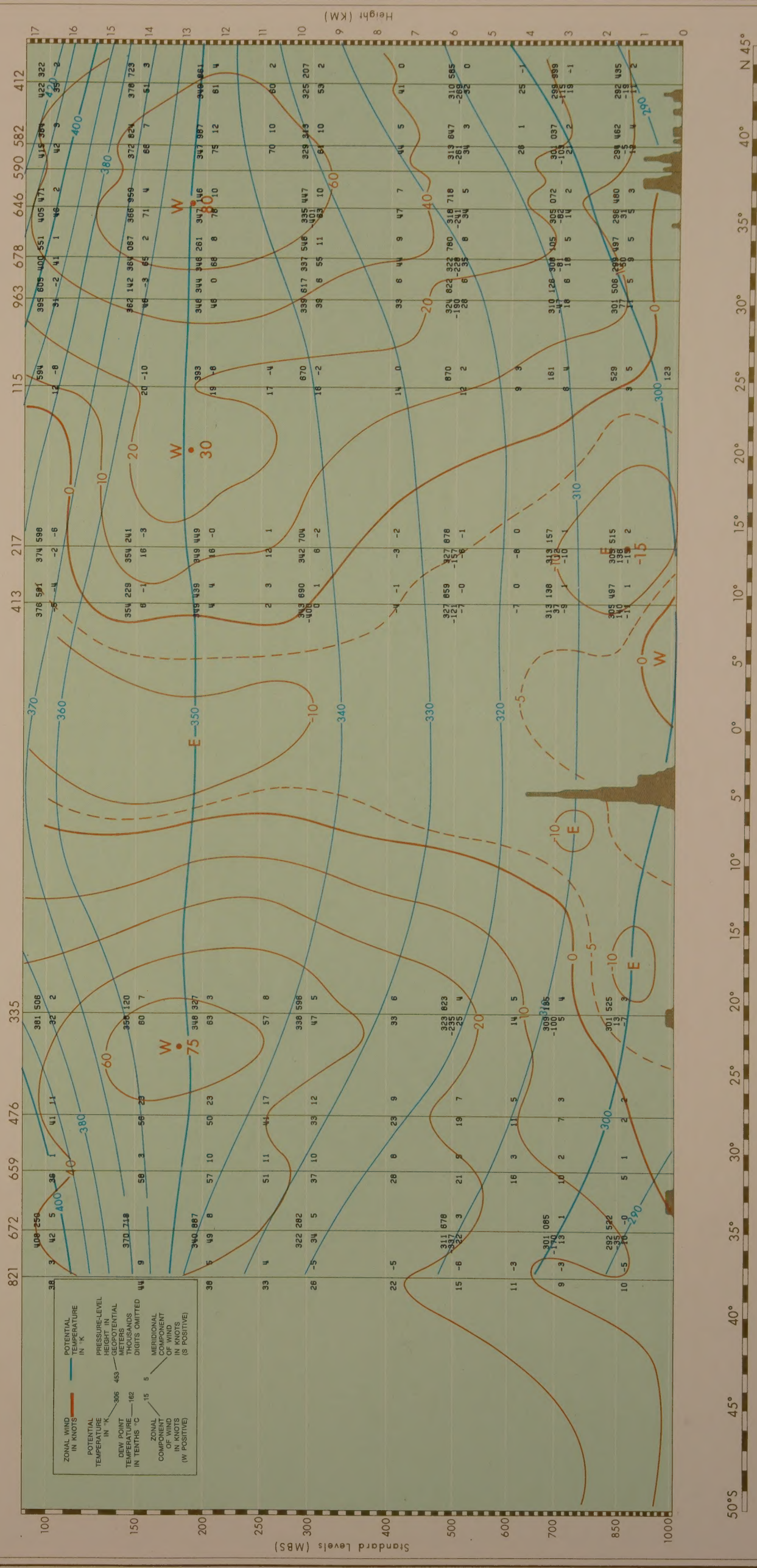
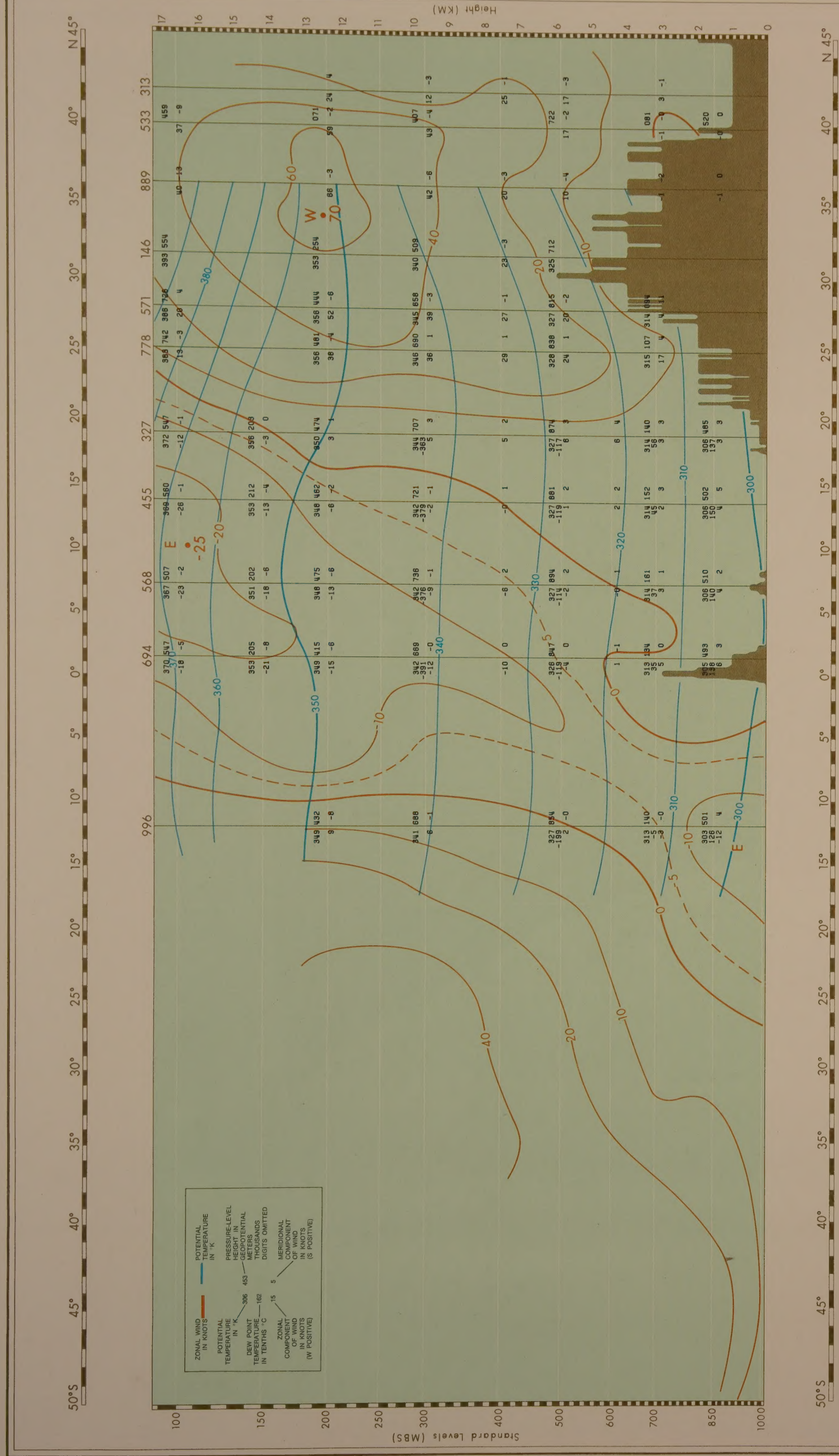


# MAY 30 E Chart 48



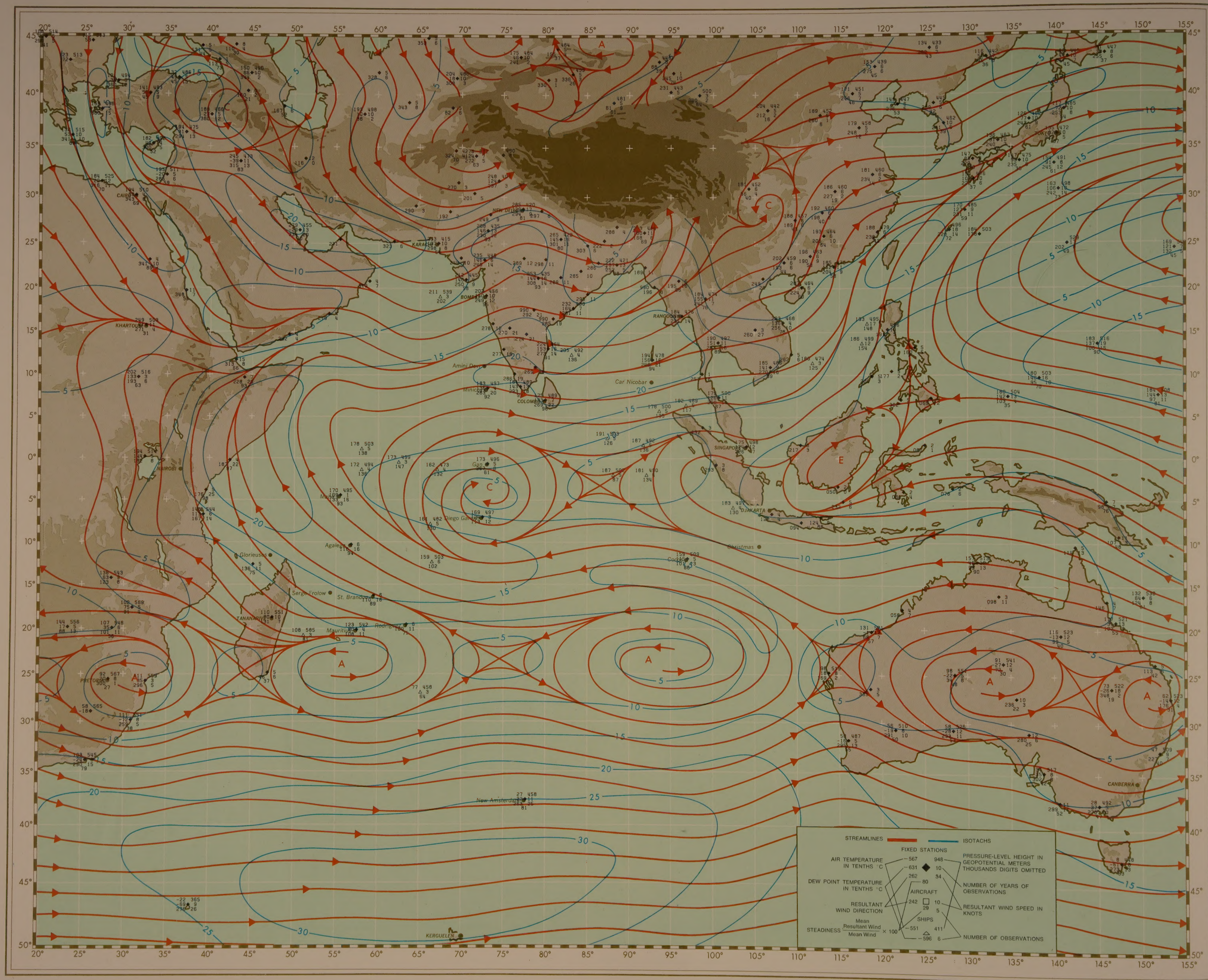
# MAY 73 E Chart 49



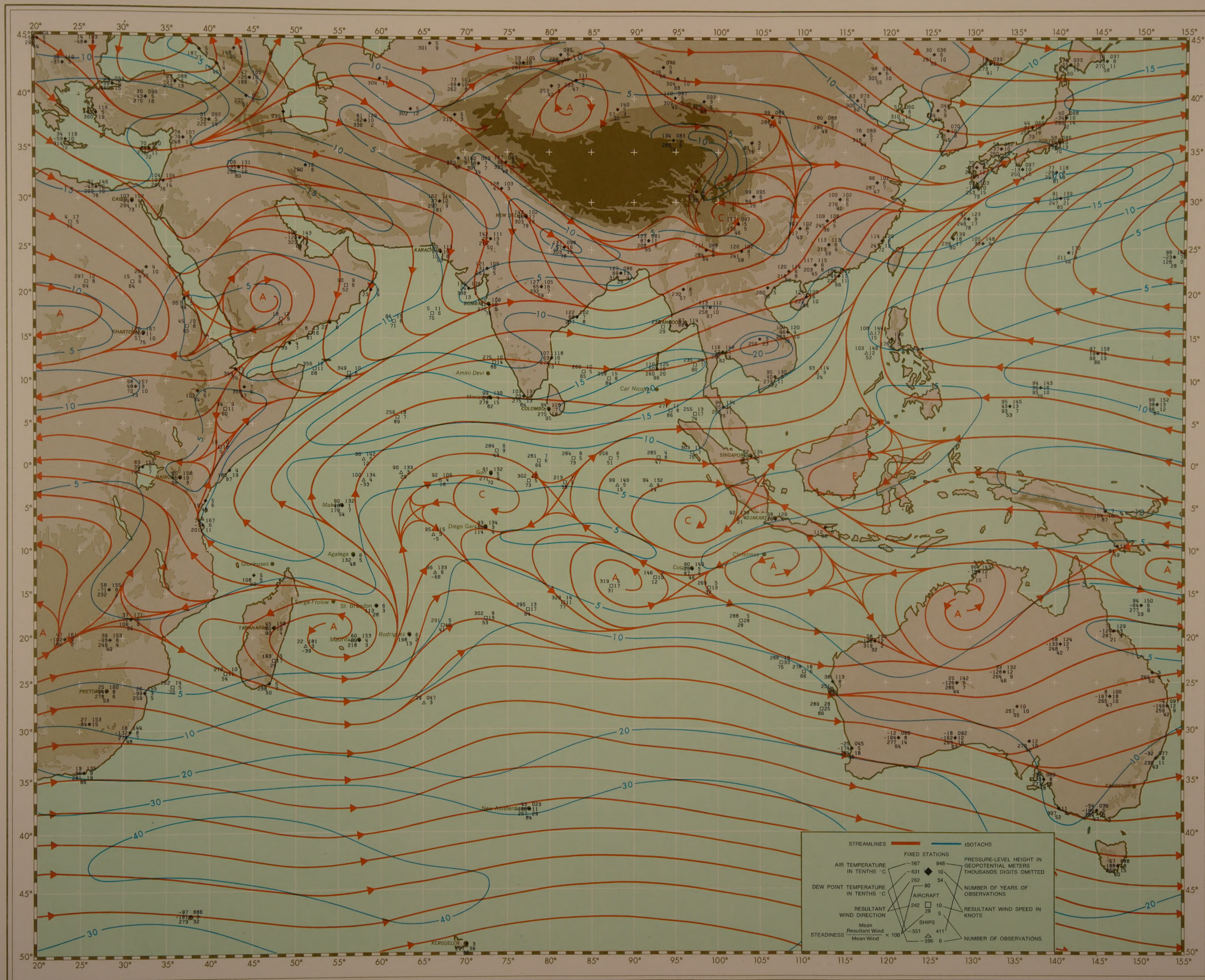




# JUNE 850 mb Chart 52

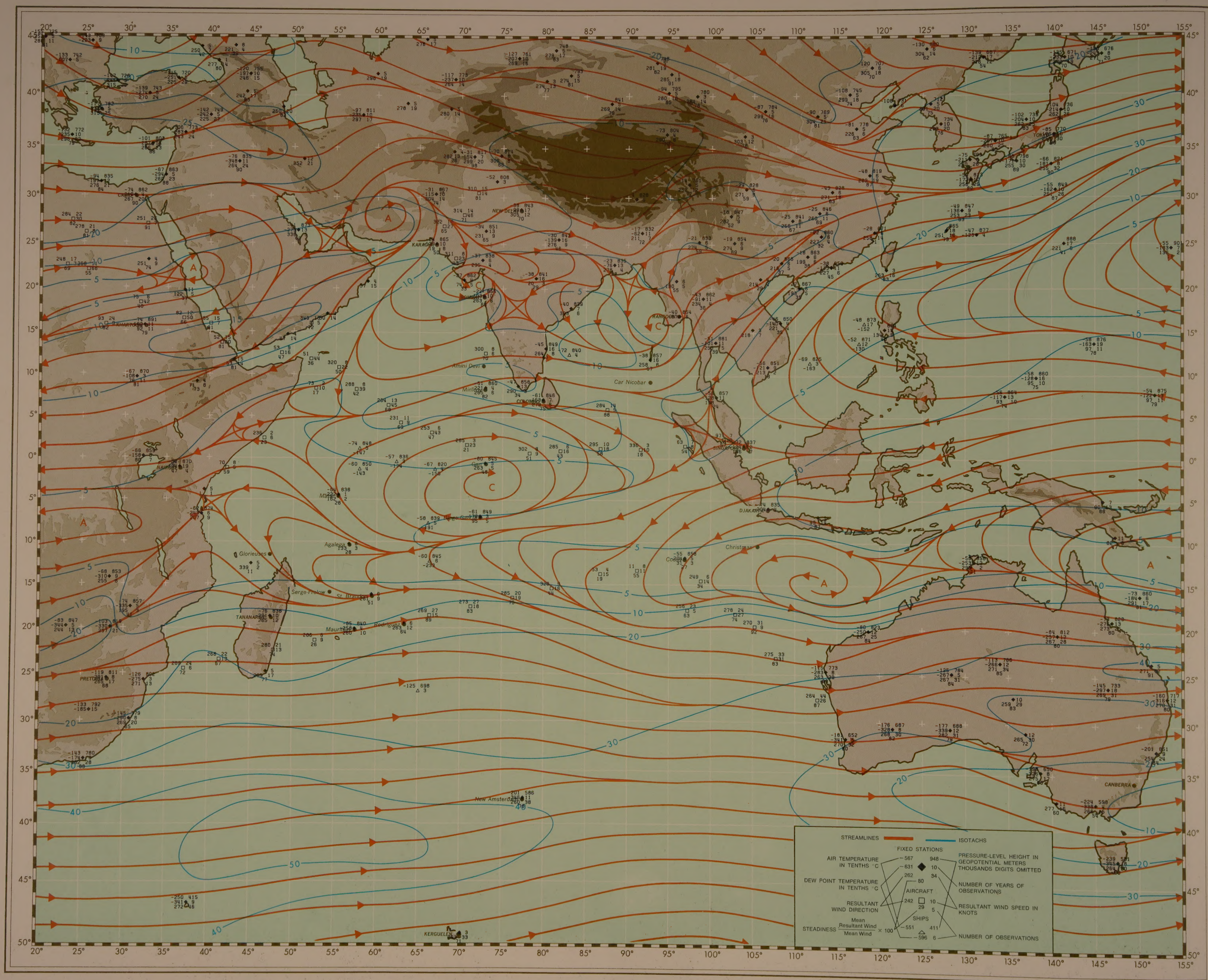




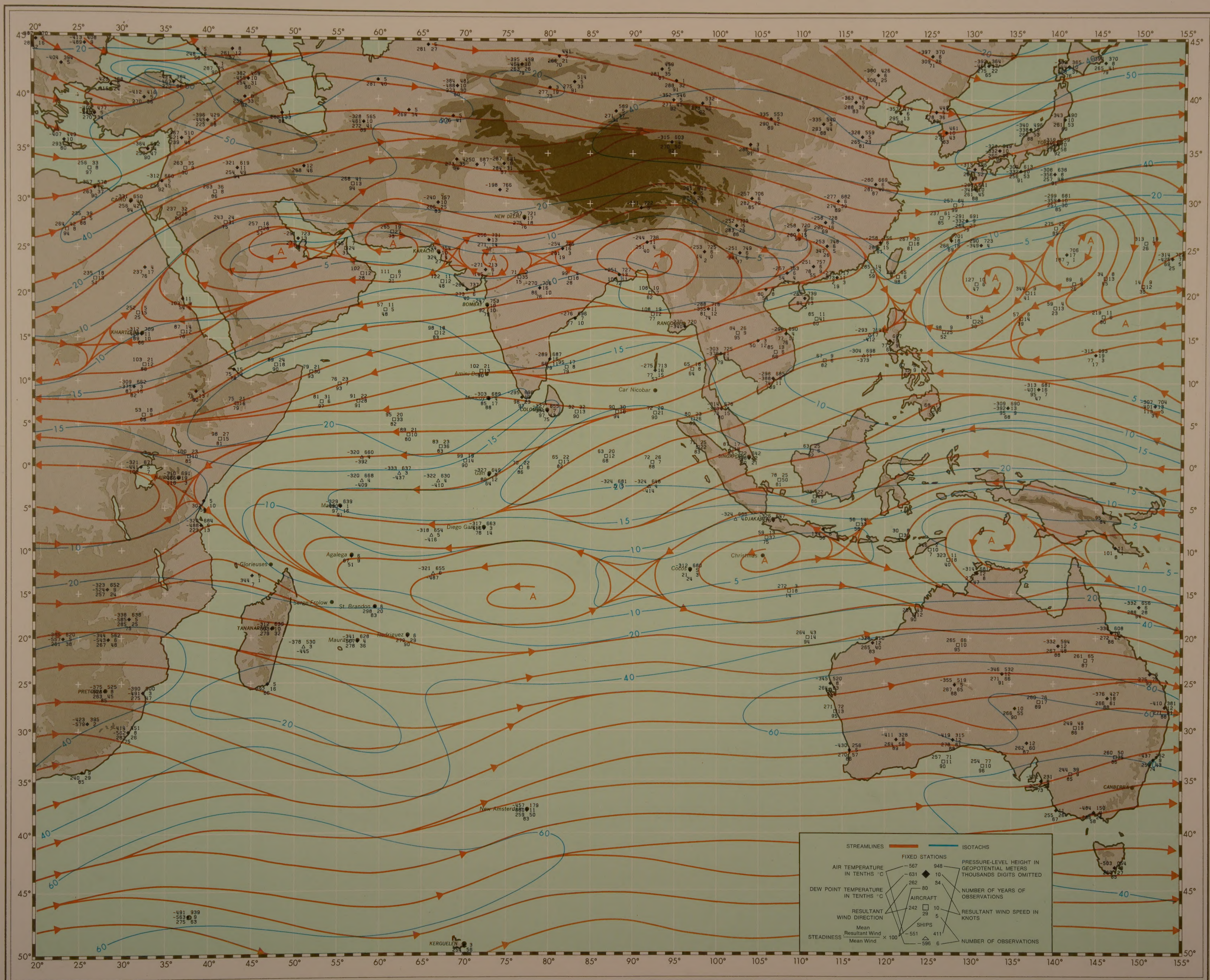




# JUNE 500 mb Chart 54

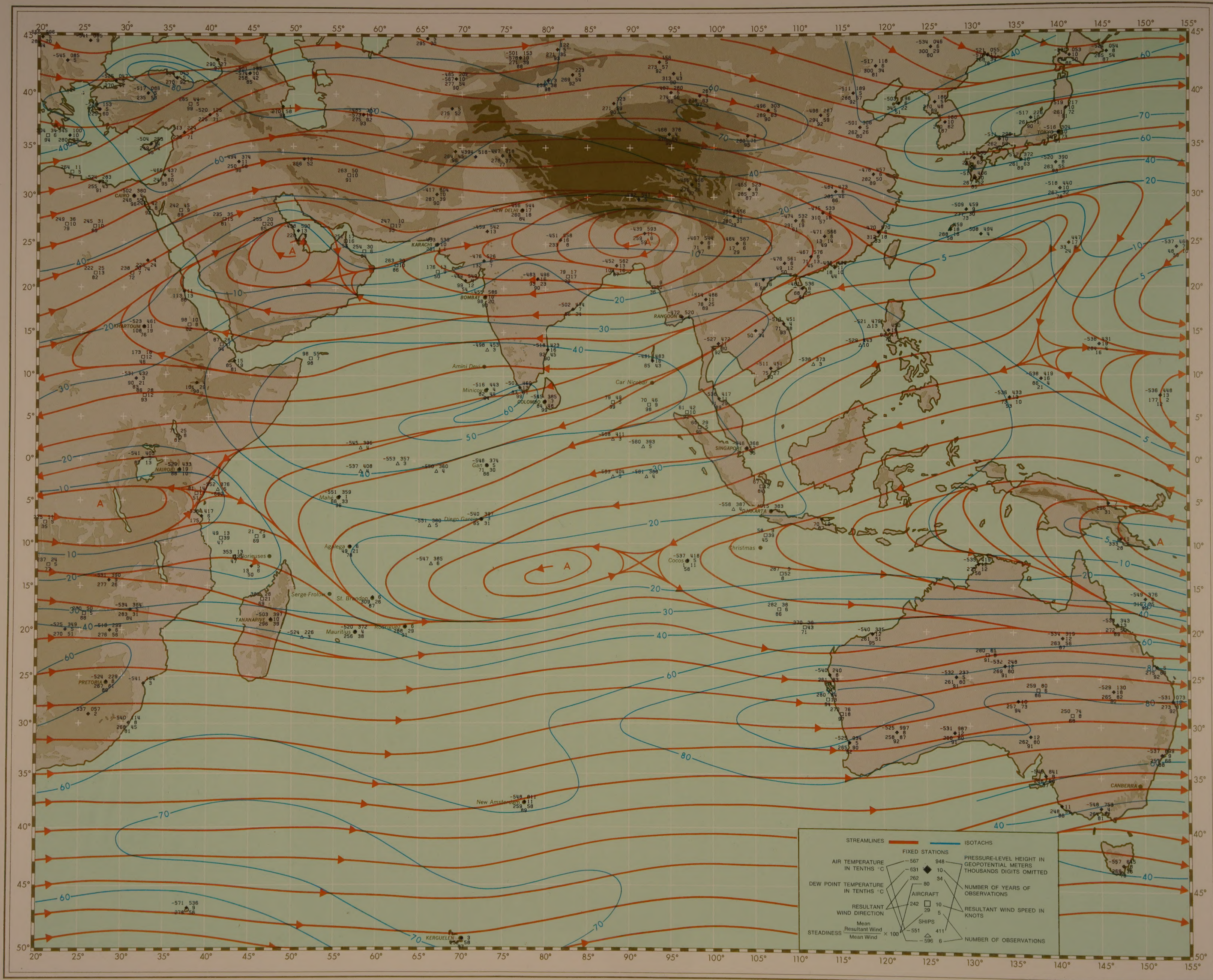




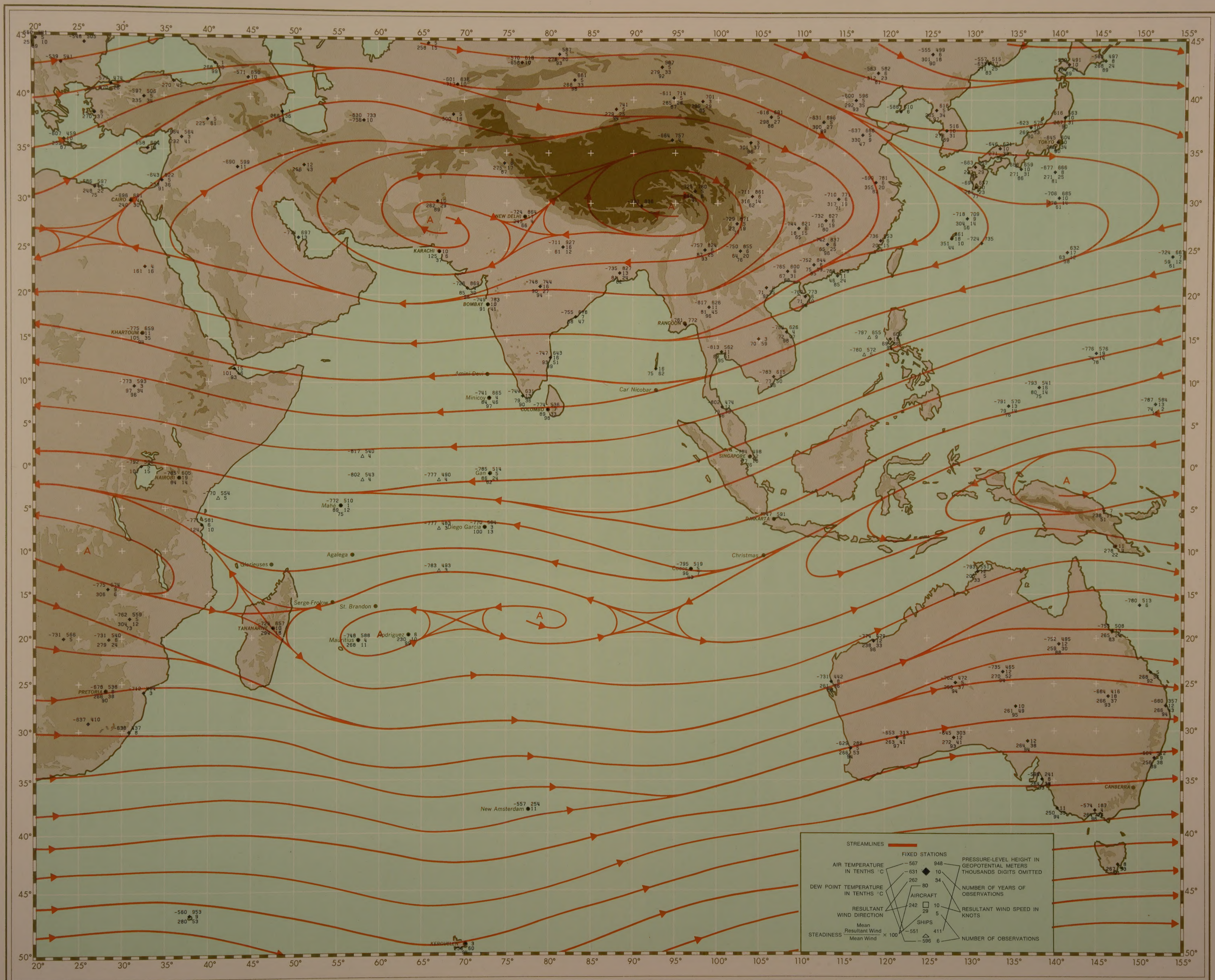




# JUNE 200 mb Chart 56

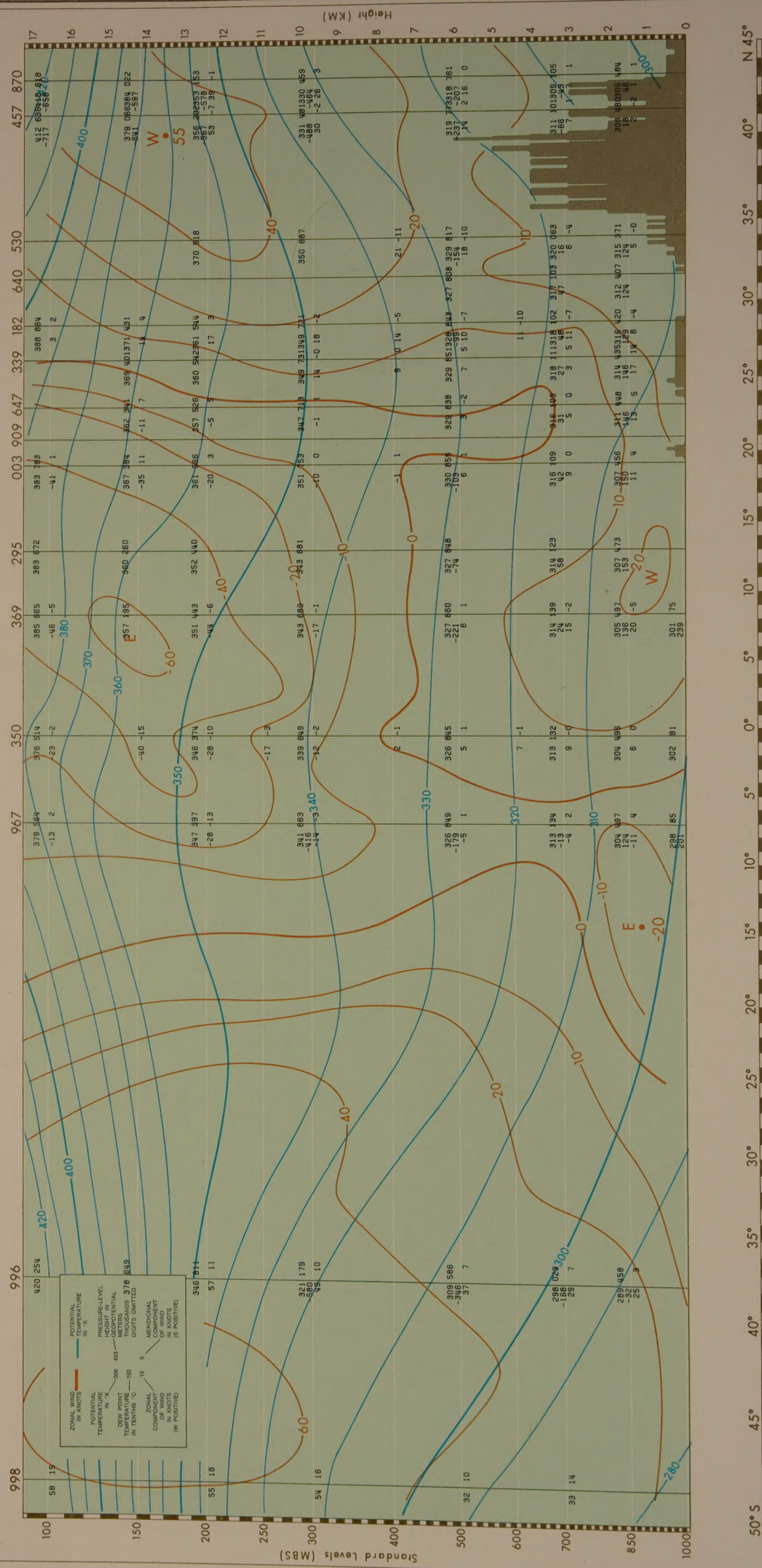
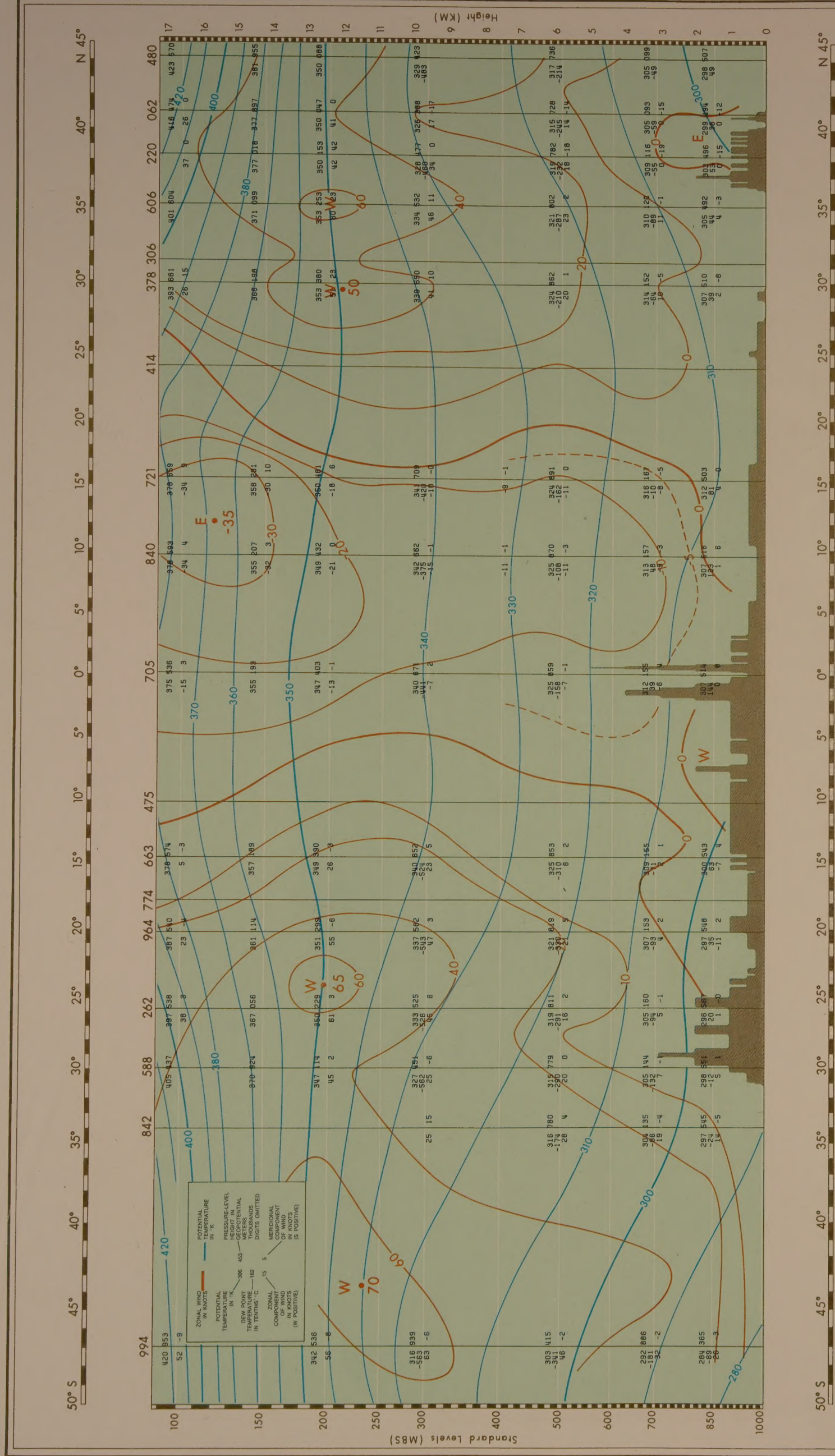






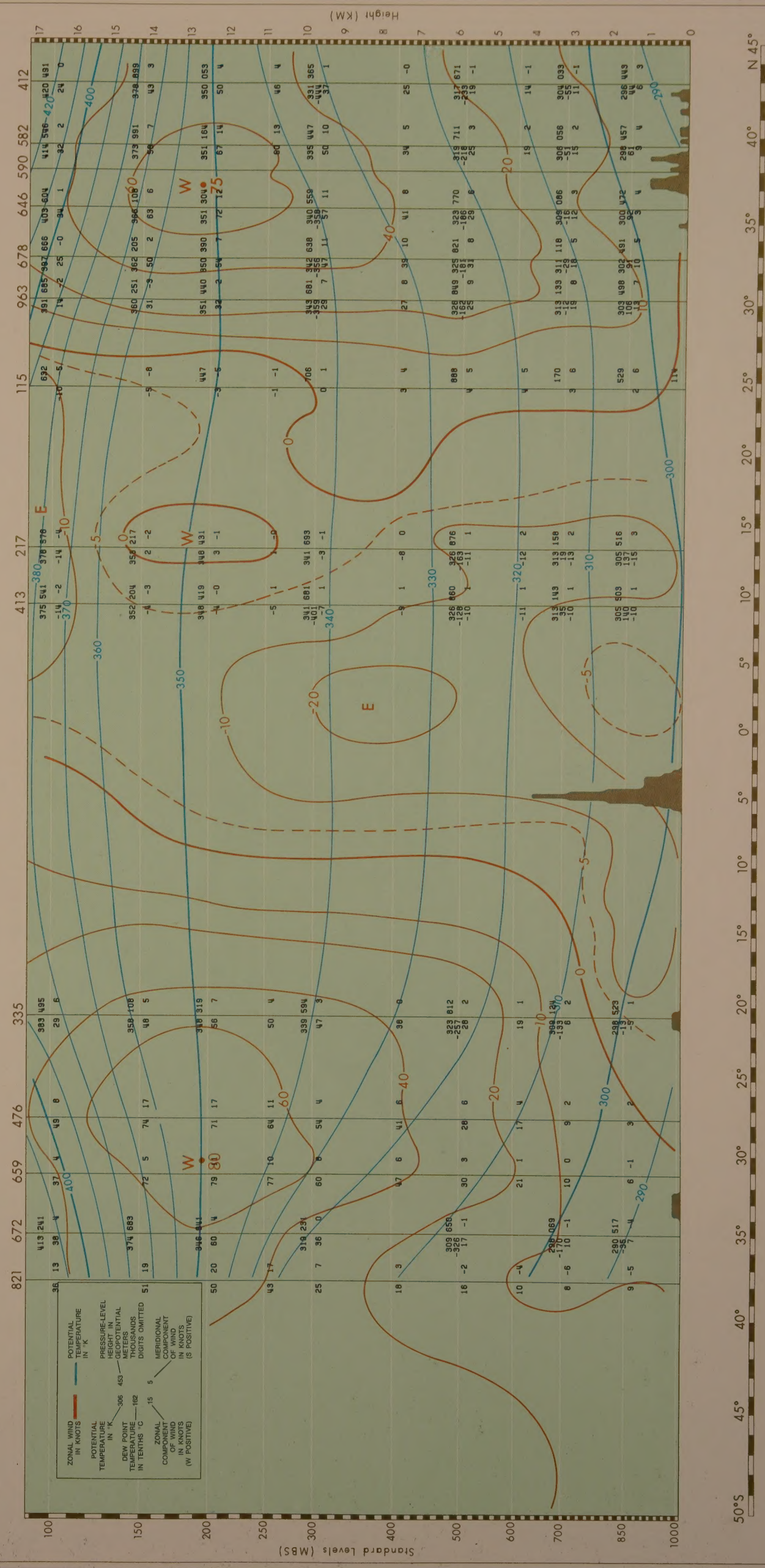
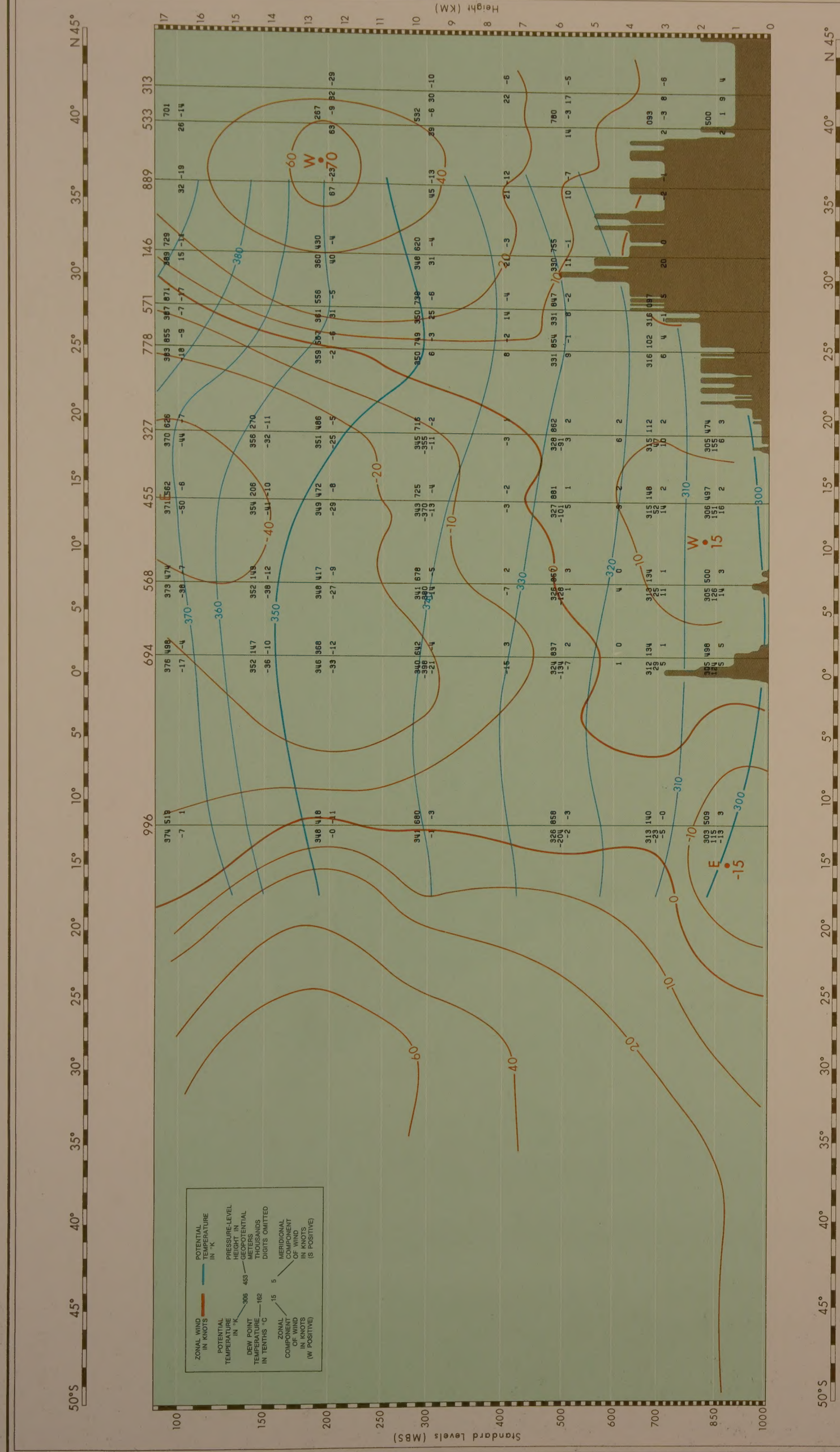


# JUNE 30 E Chart 58



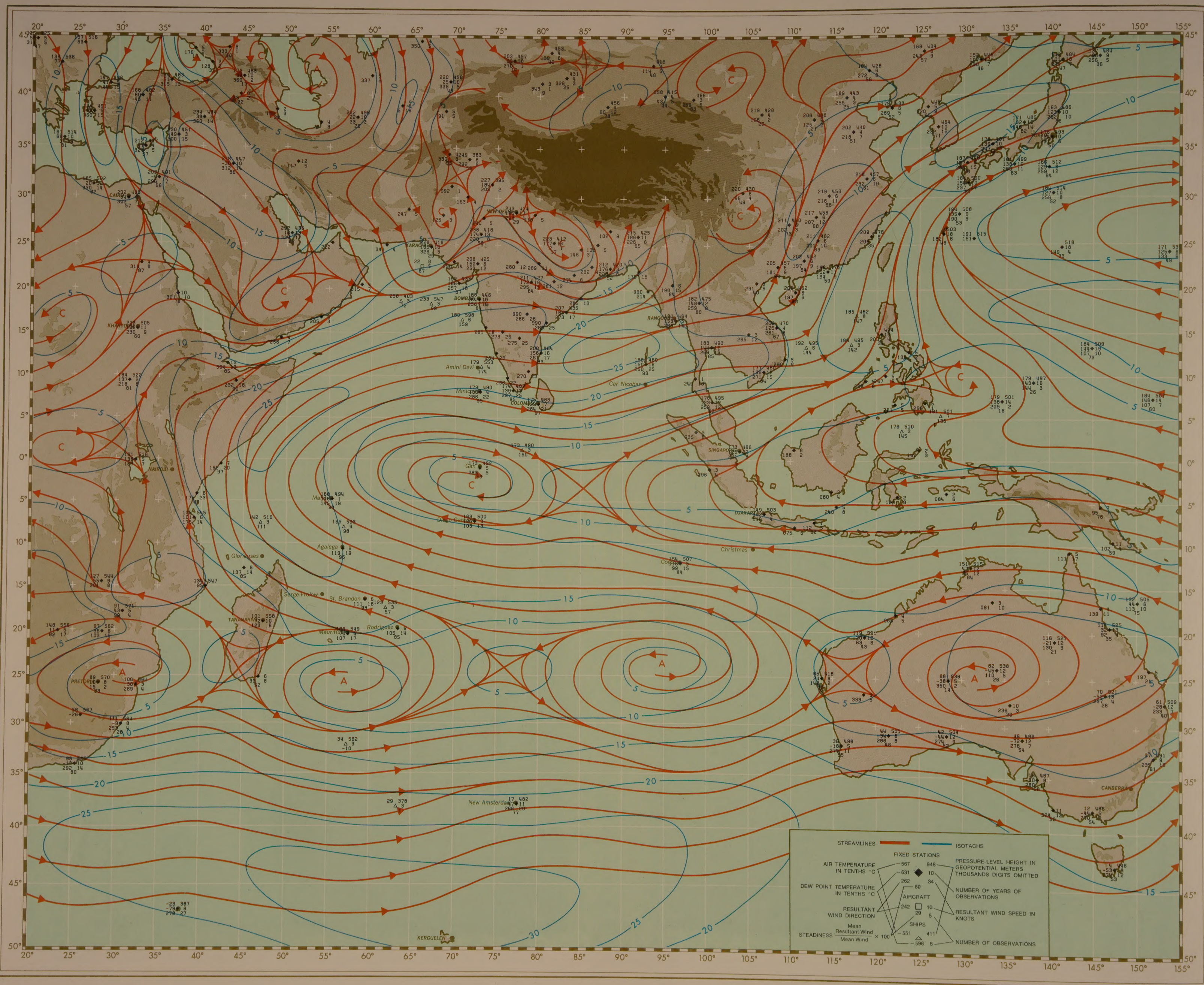
# JUNE 73 E Chart 59



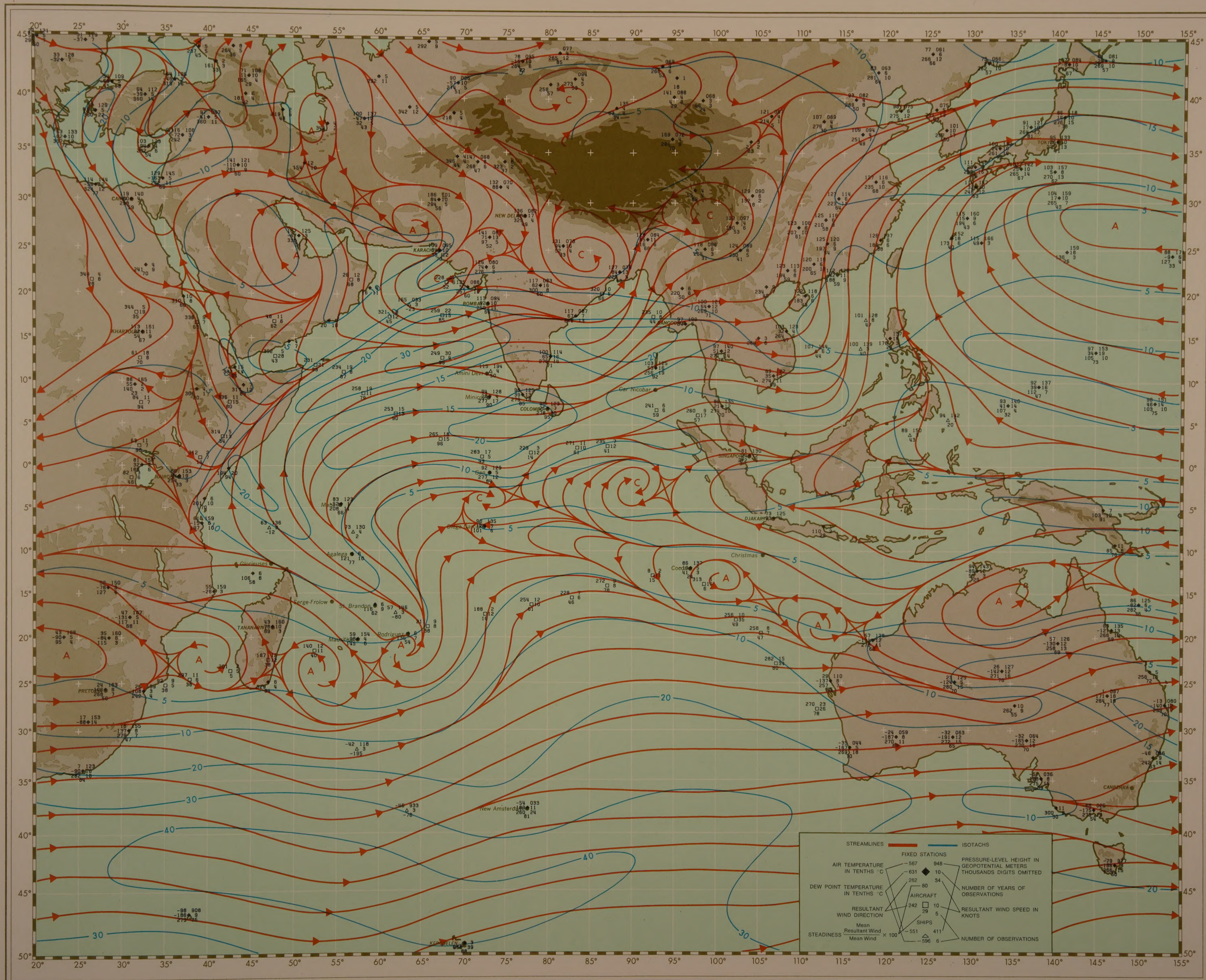




# JULY 850 mb Chart 62

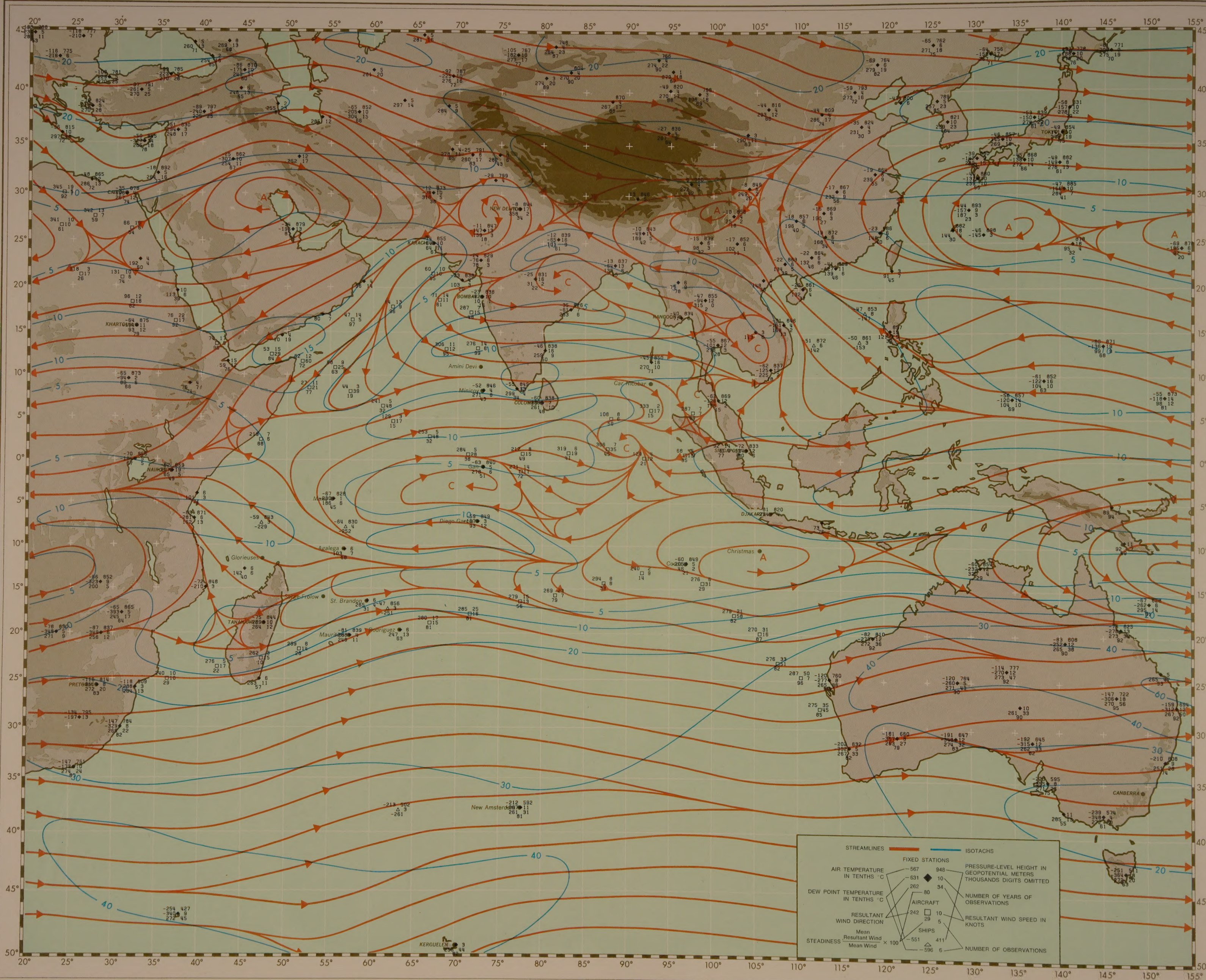




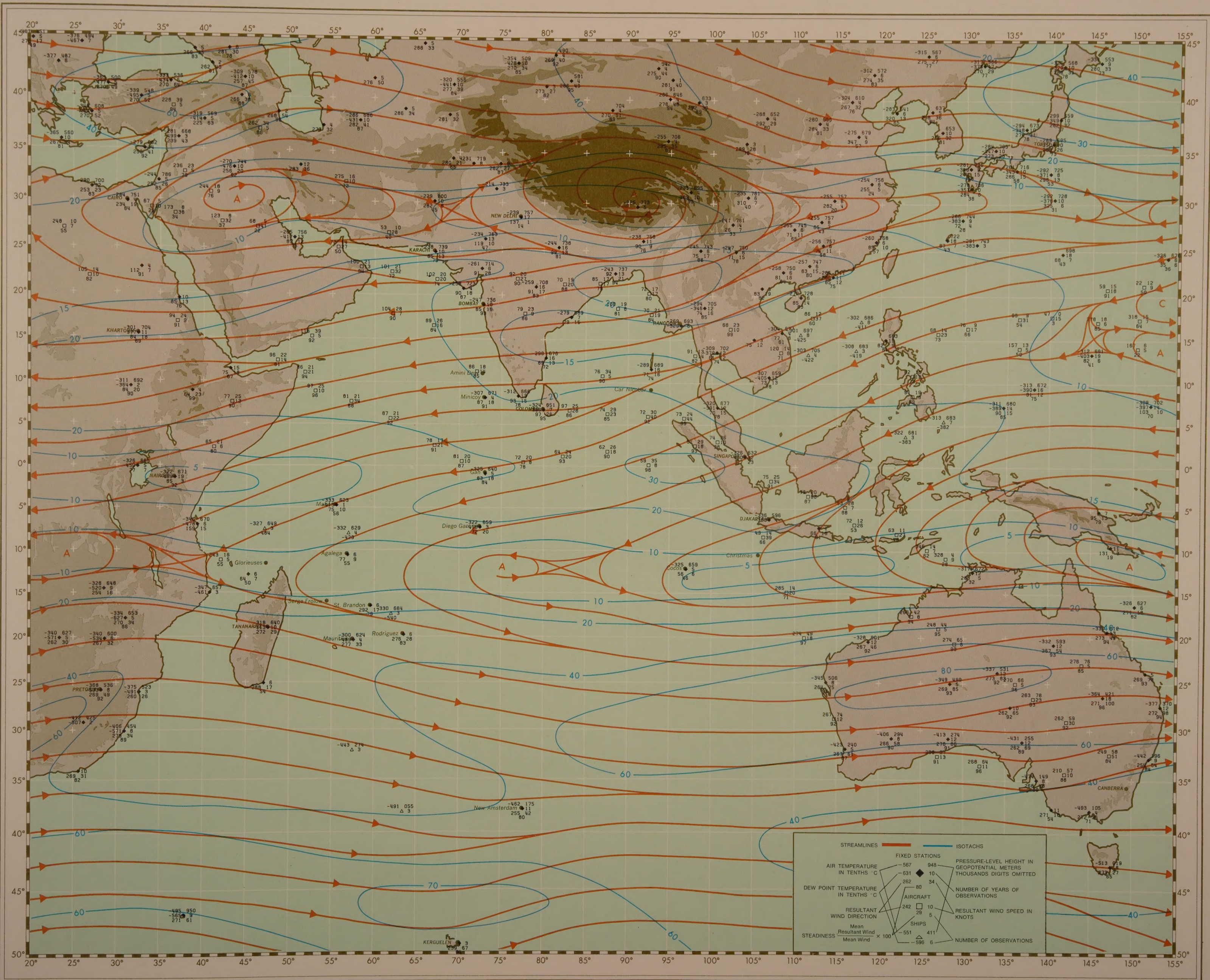




### Chart 64

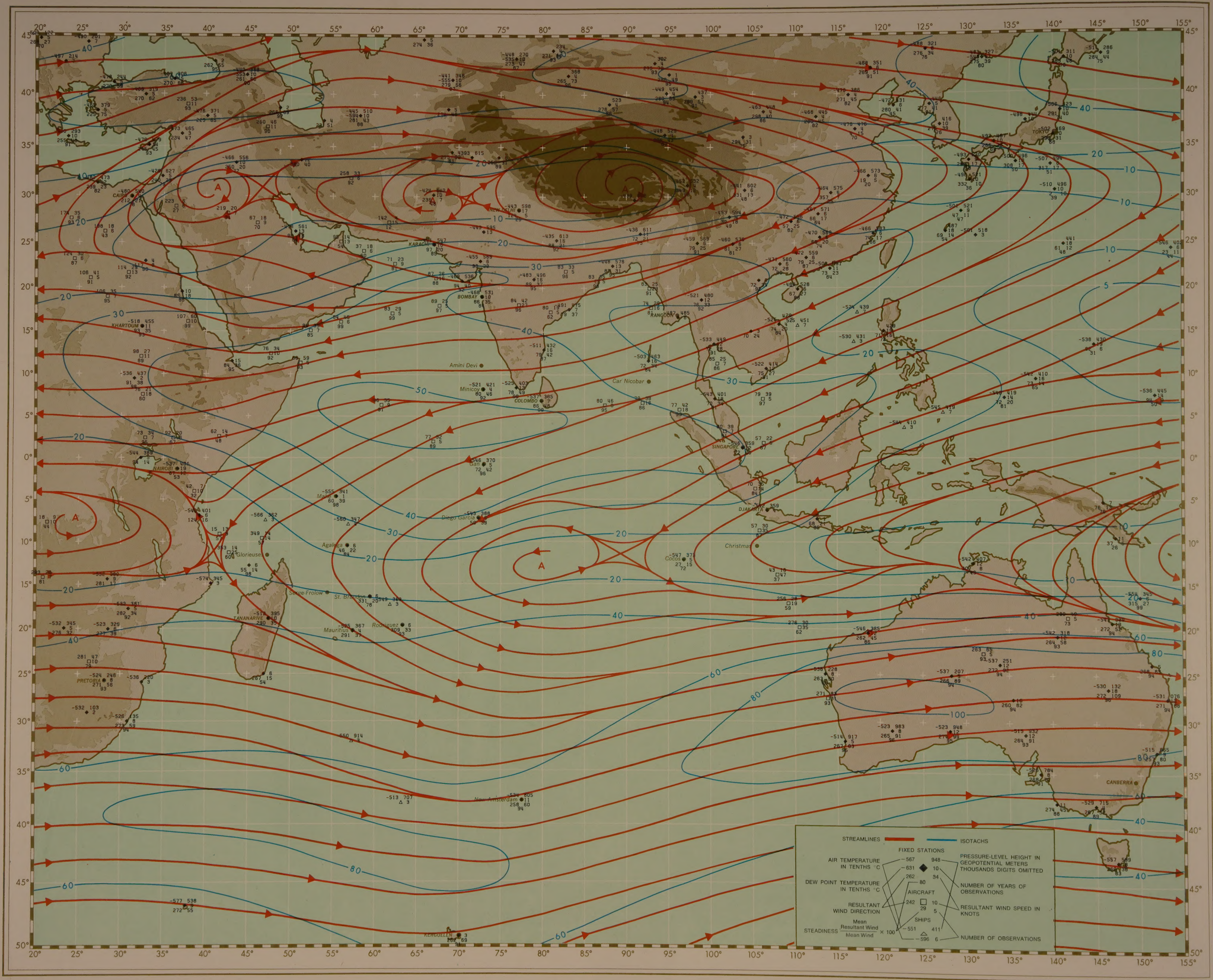




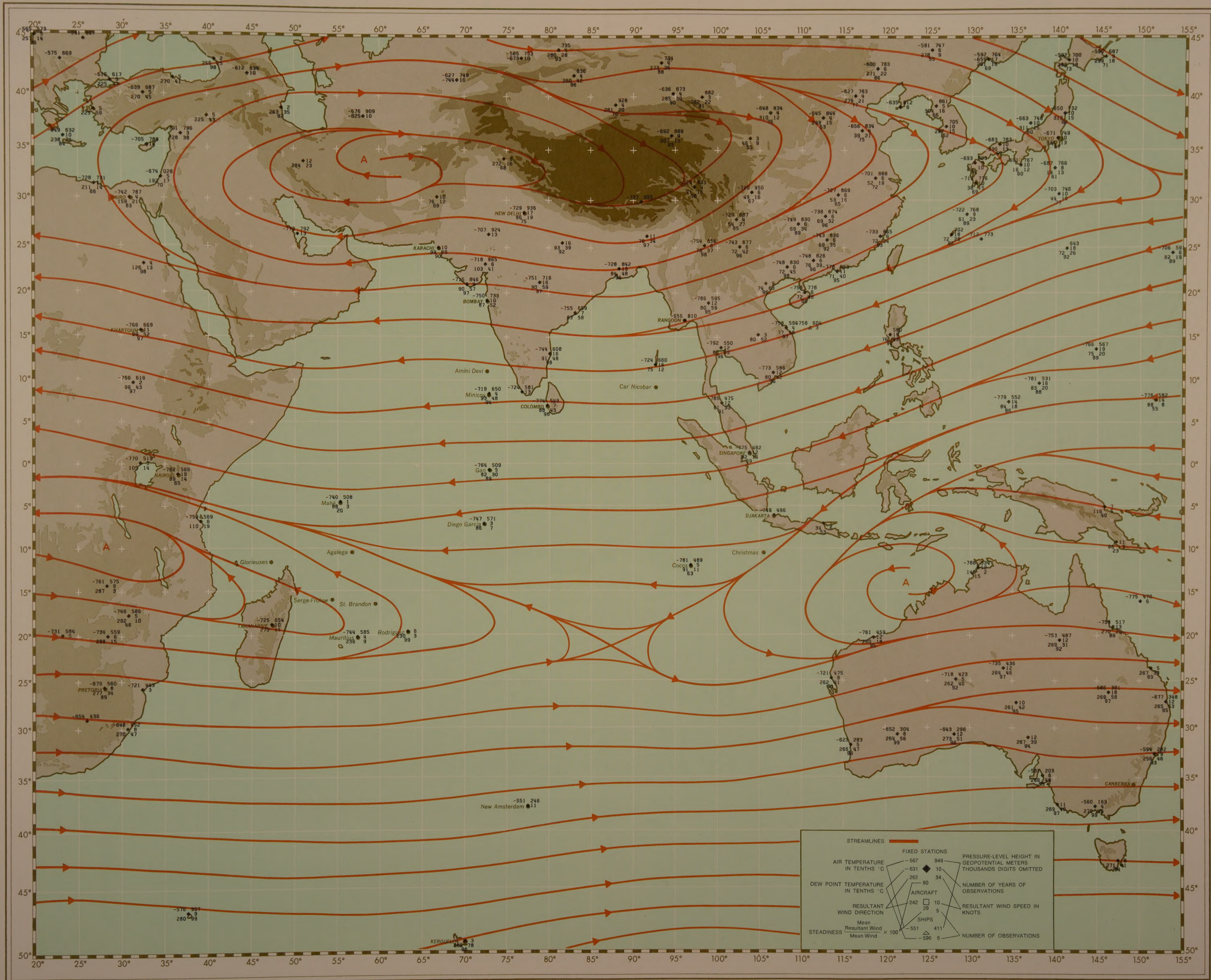




# JULY 200 mb Chart 66

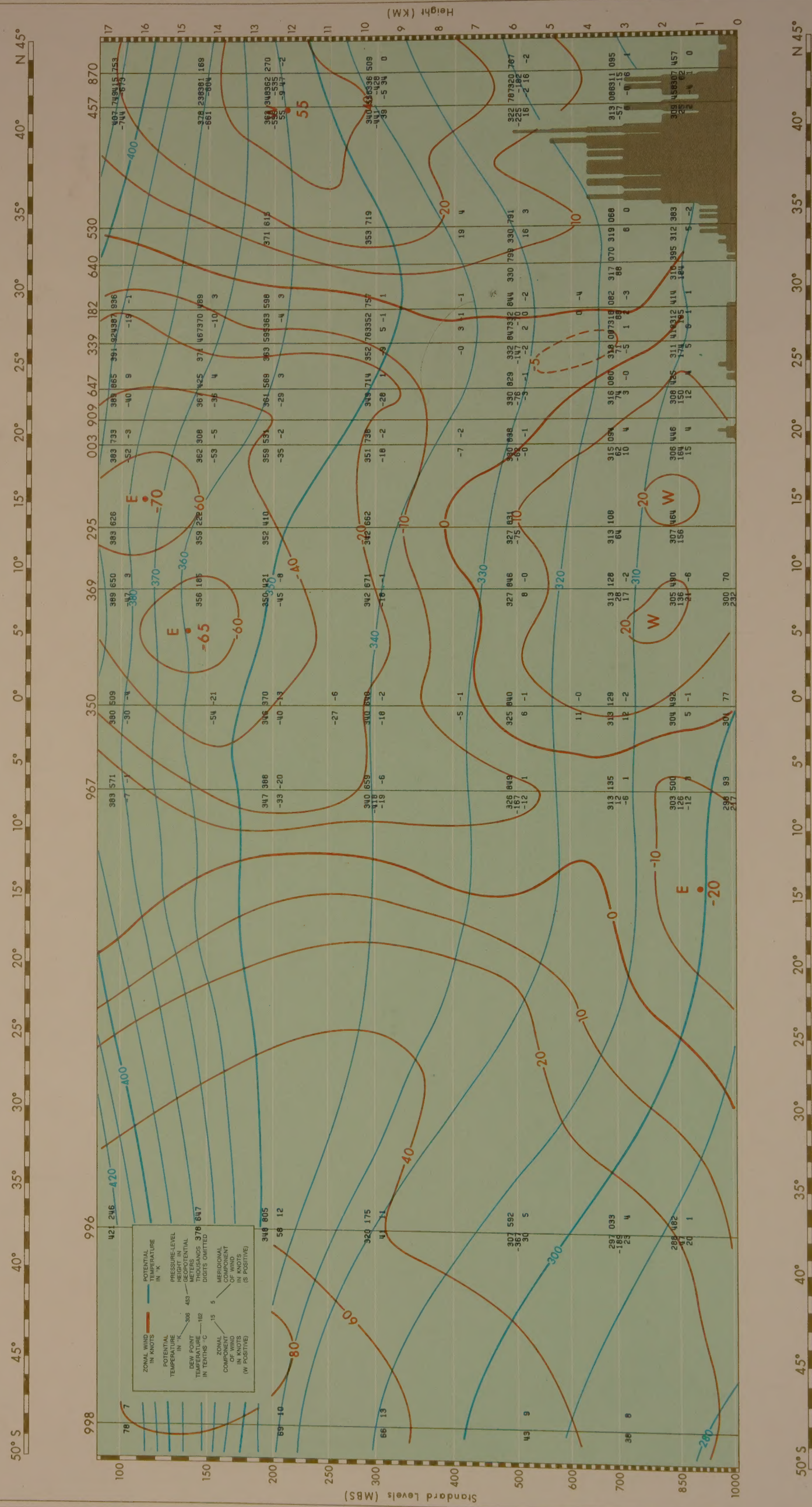
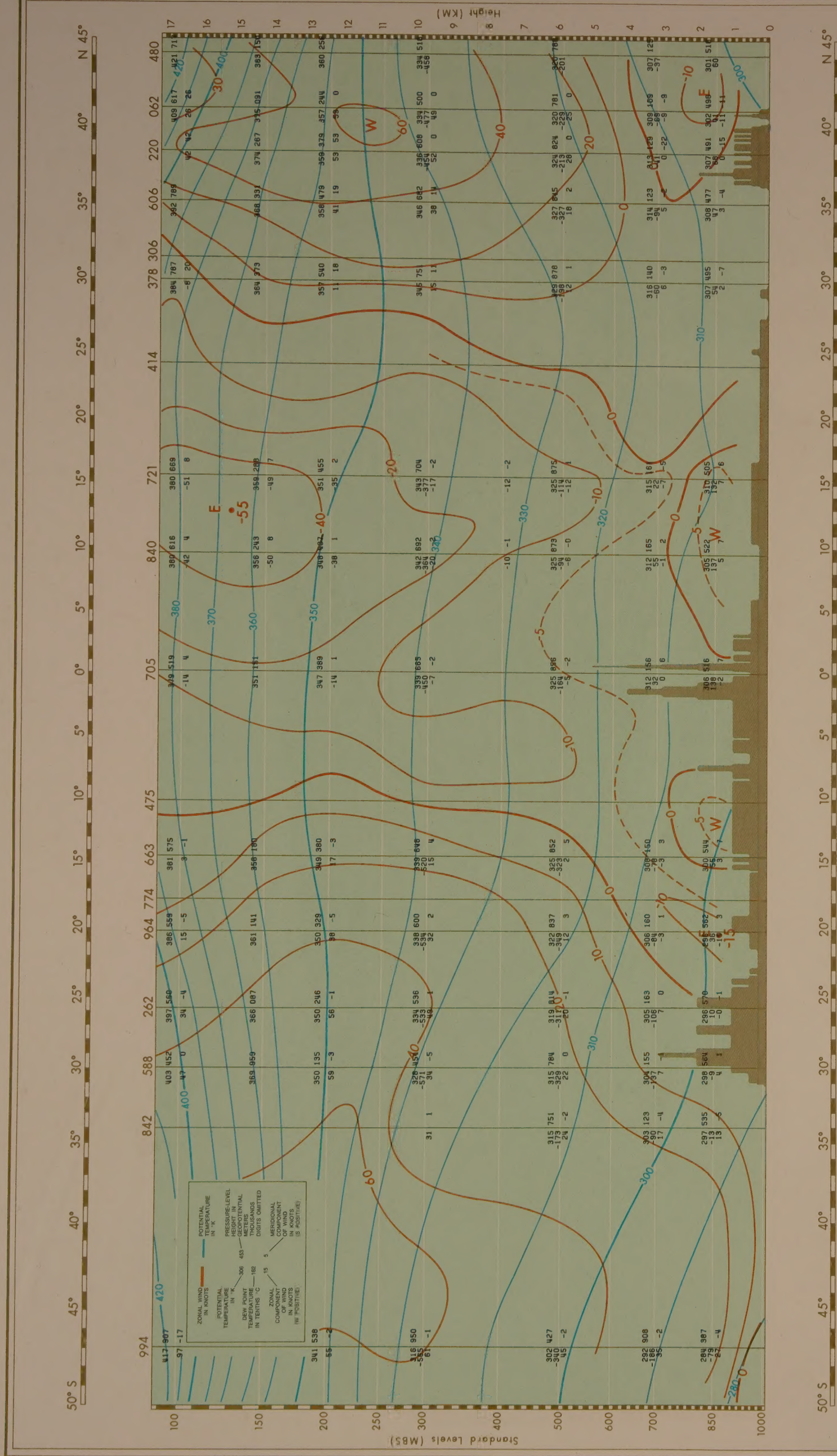






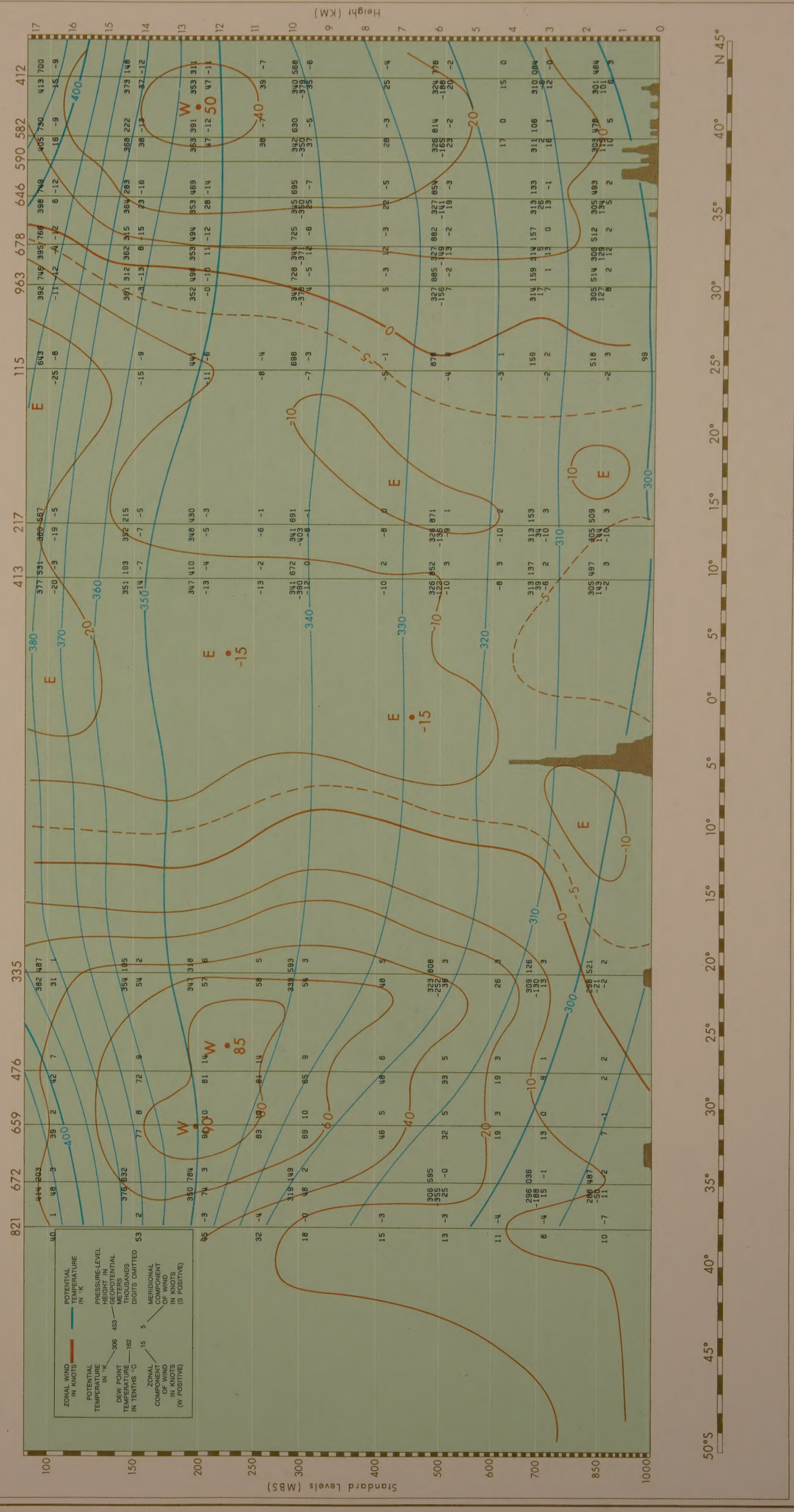
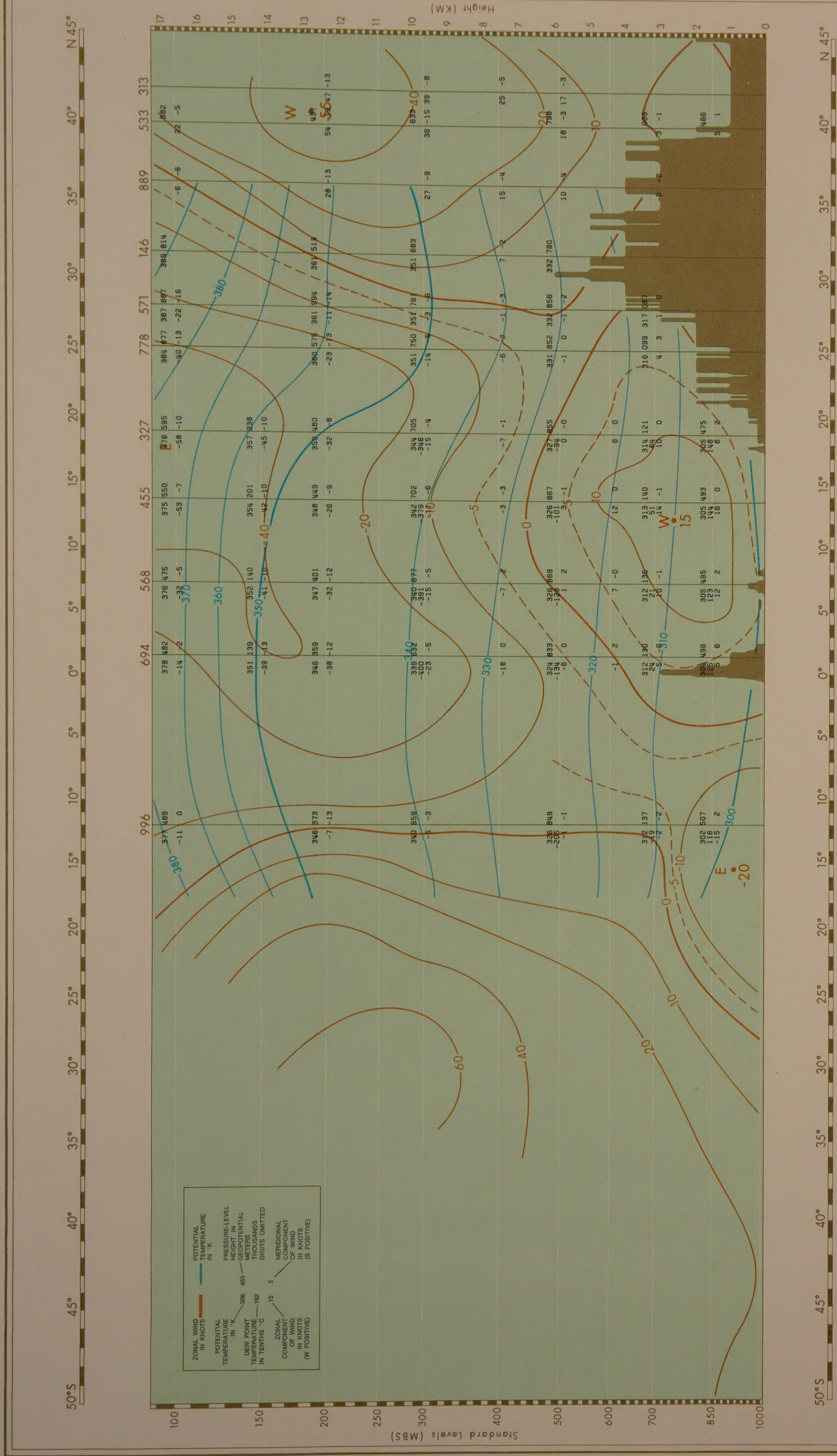


## JULY 30 E Chart 68

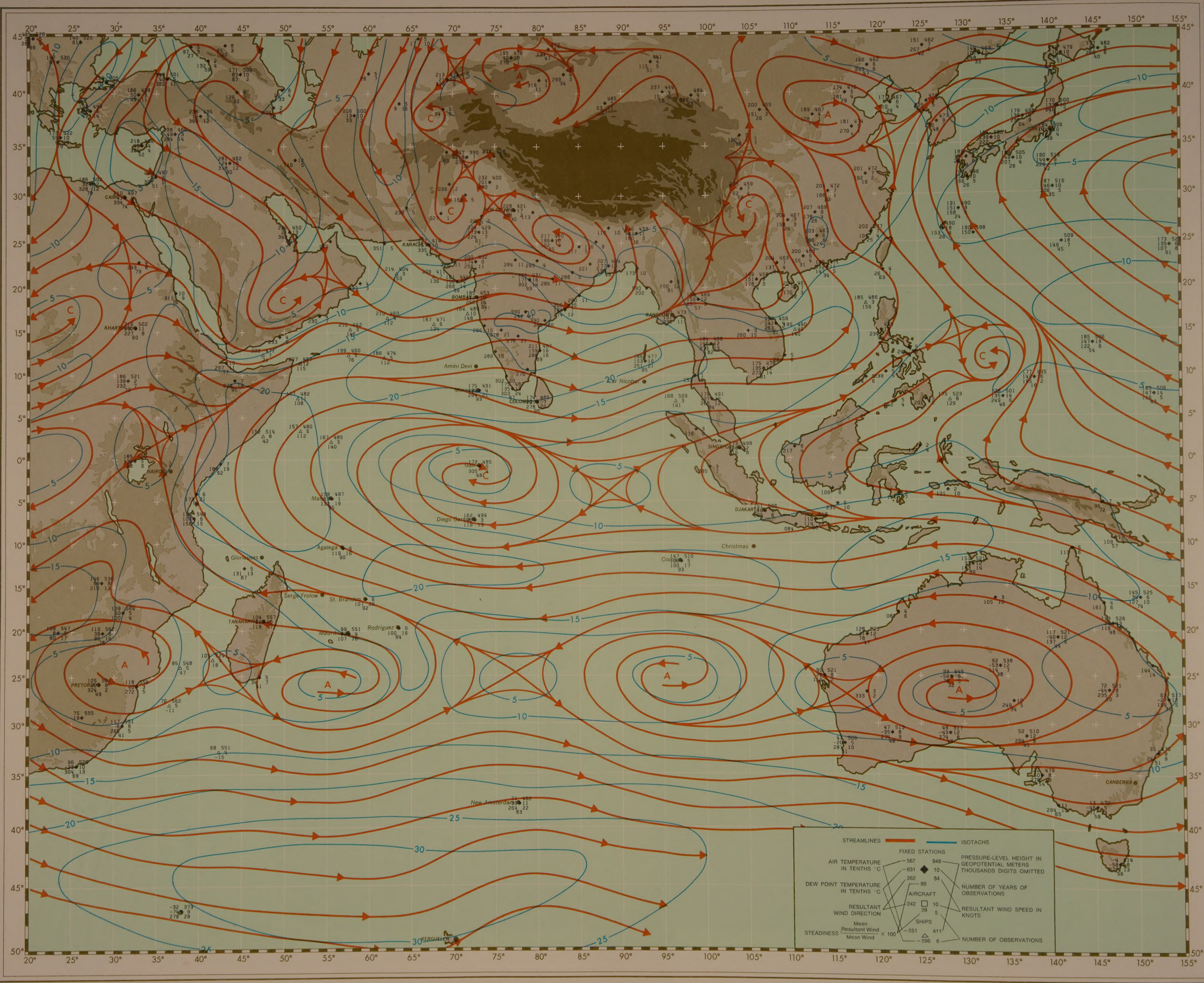


## JULY 73 E Chart 69



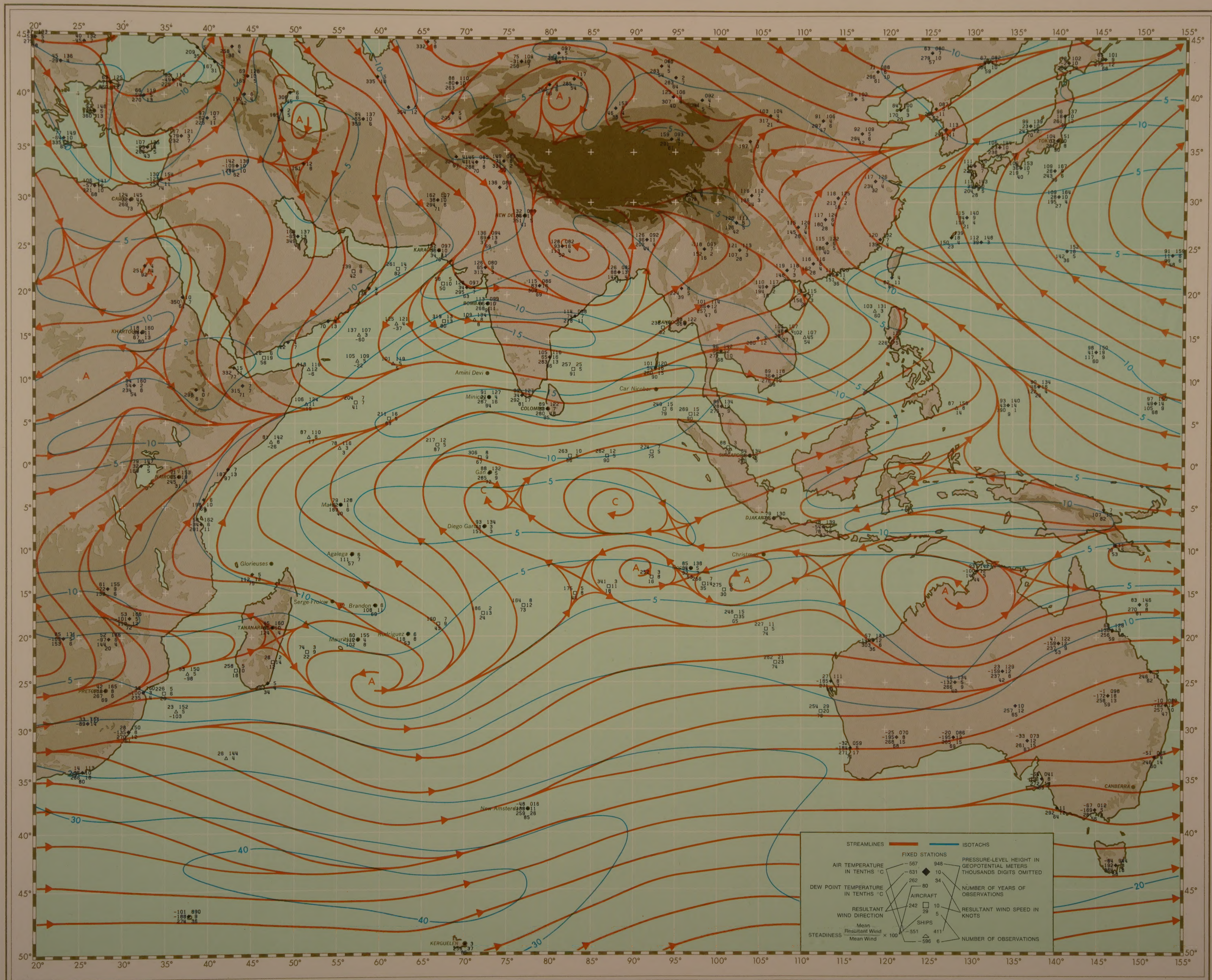






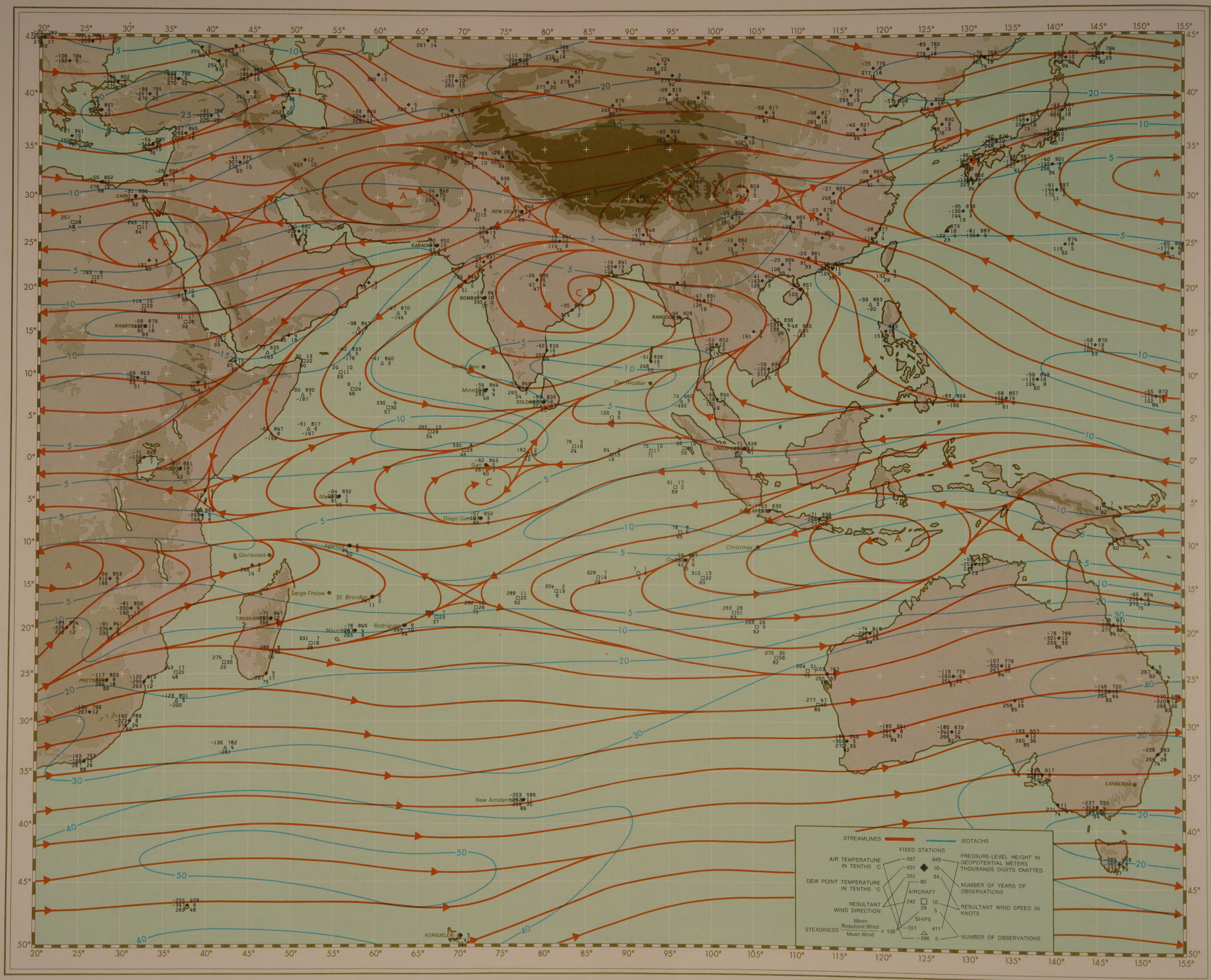


# AUGUST 700 mb Chart 73



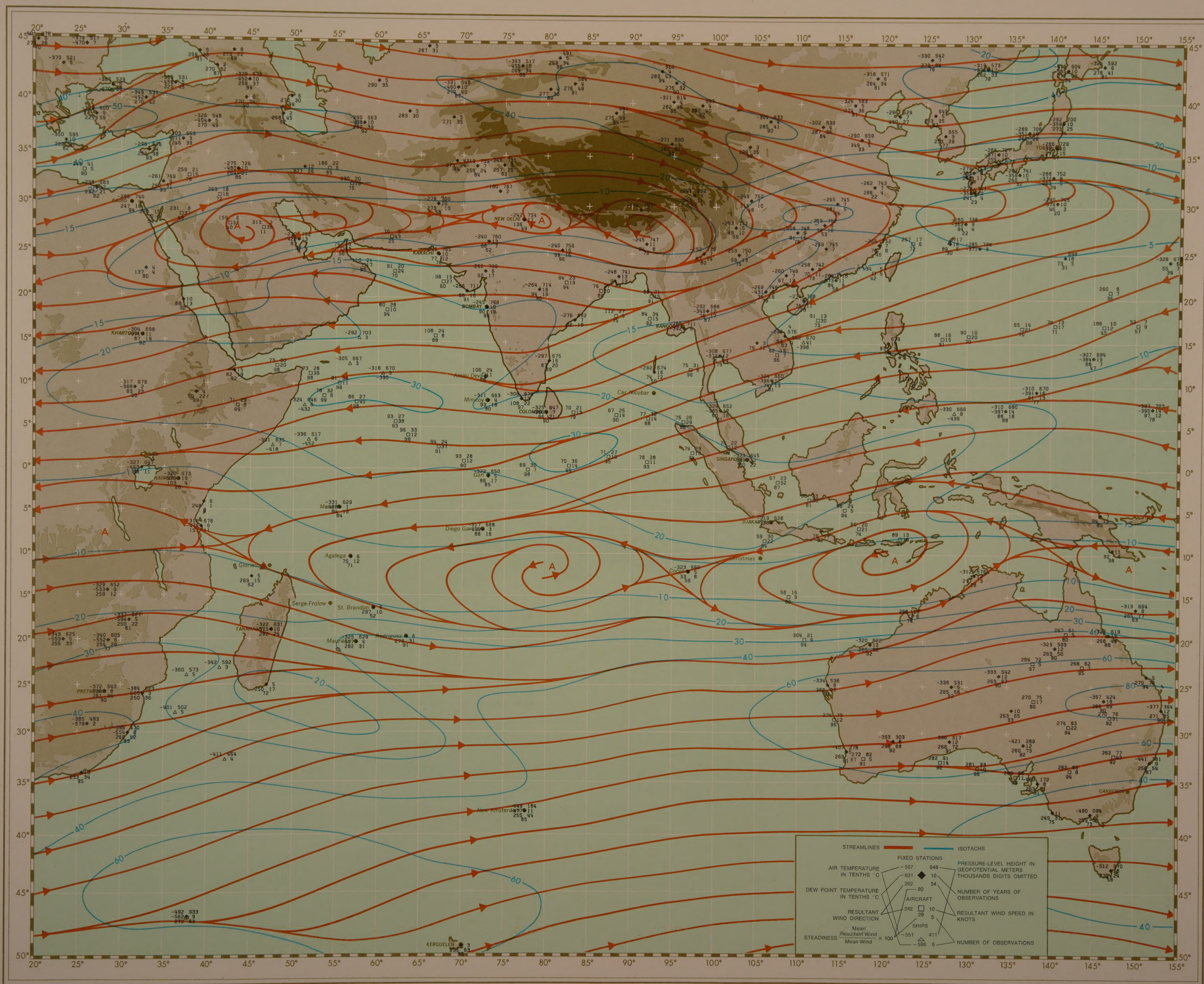


# AUGUST 500 mb Chart 74



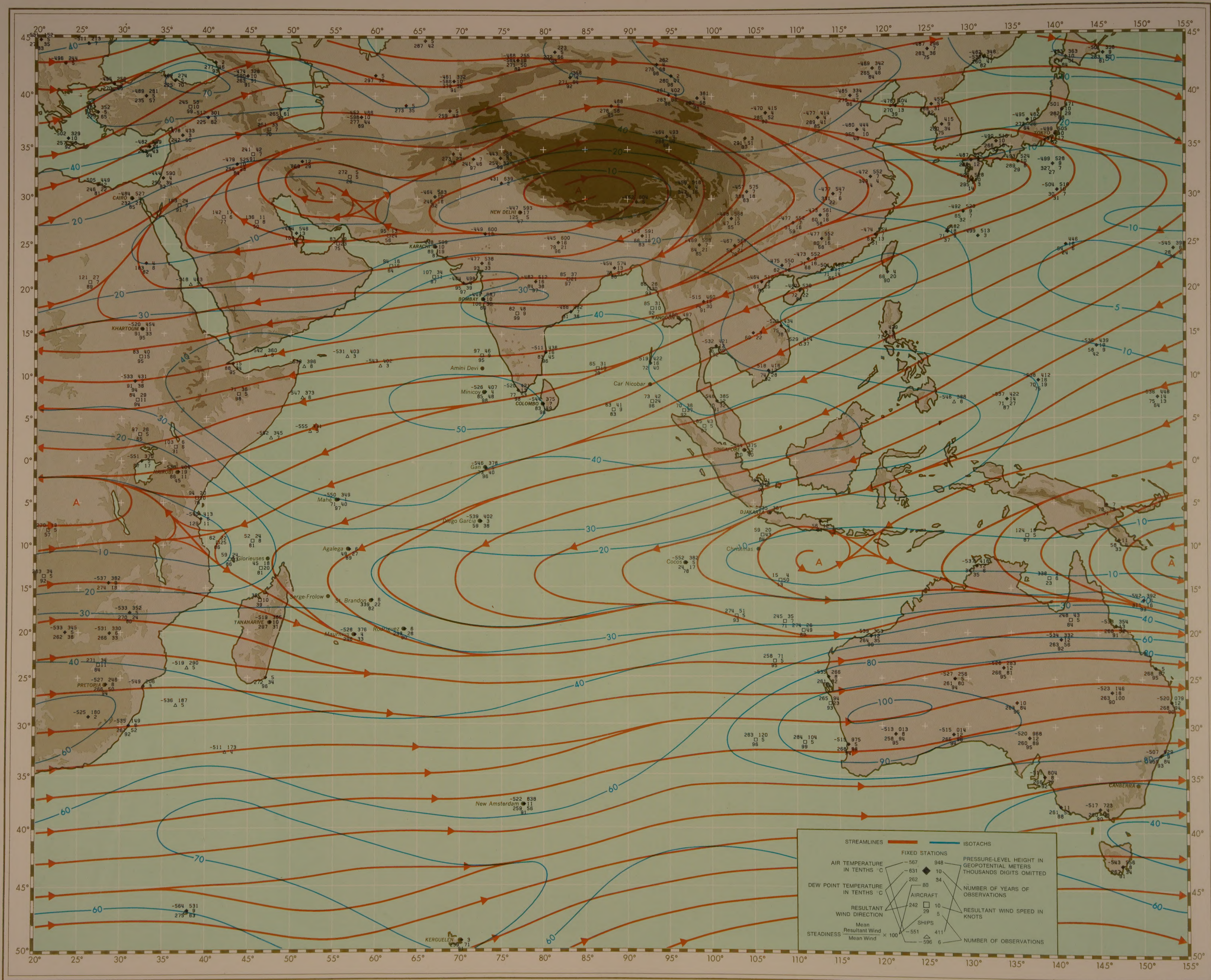


# AUGUST 300 mb Chart 75



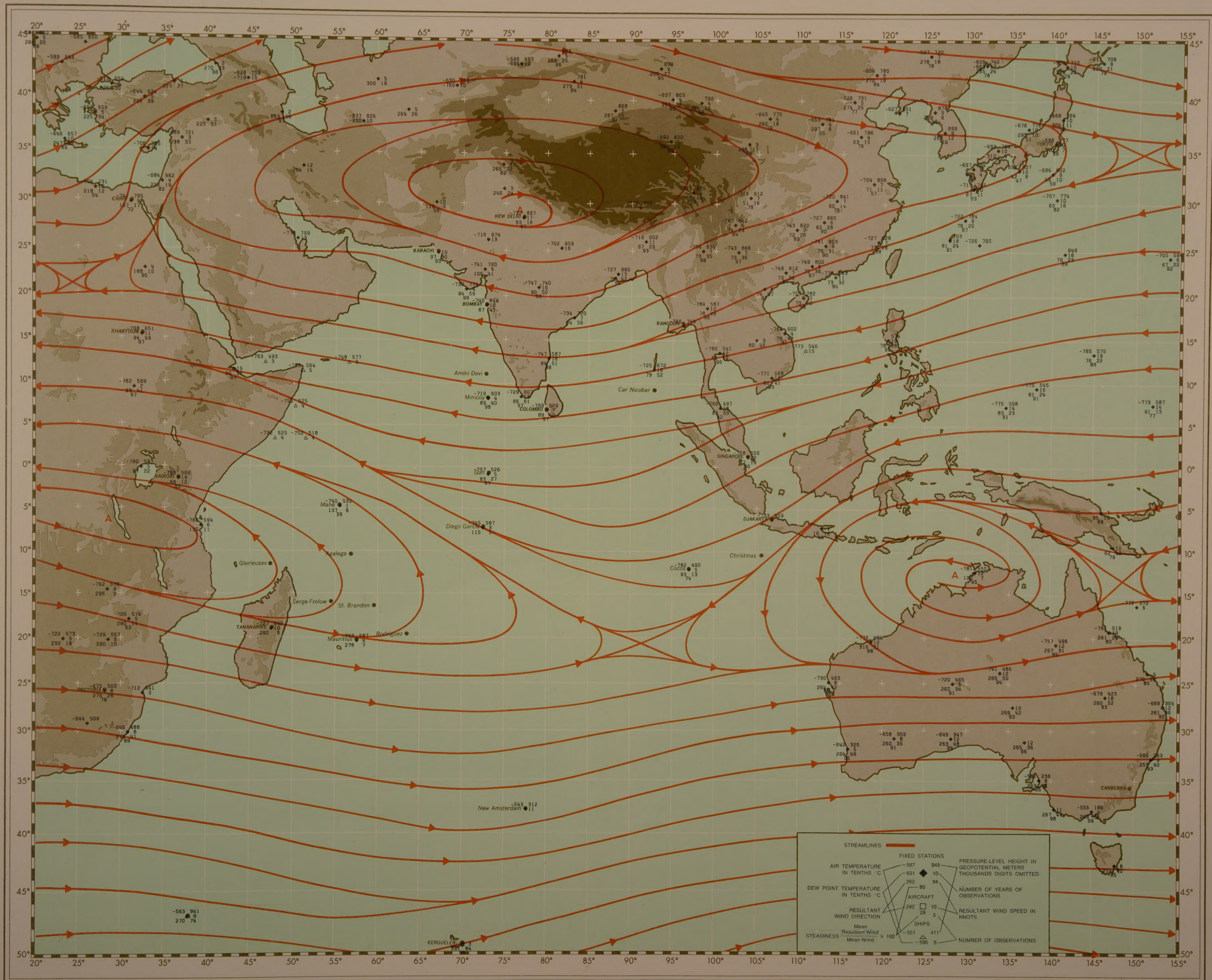


# AUGUST 200 mb Chart 76



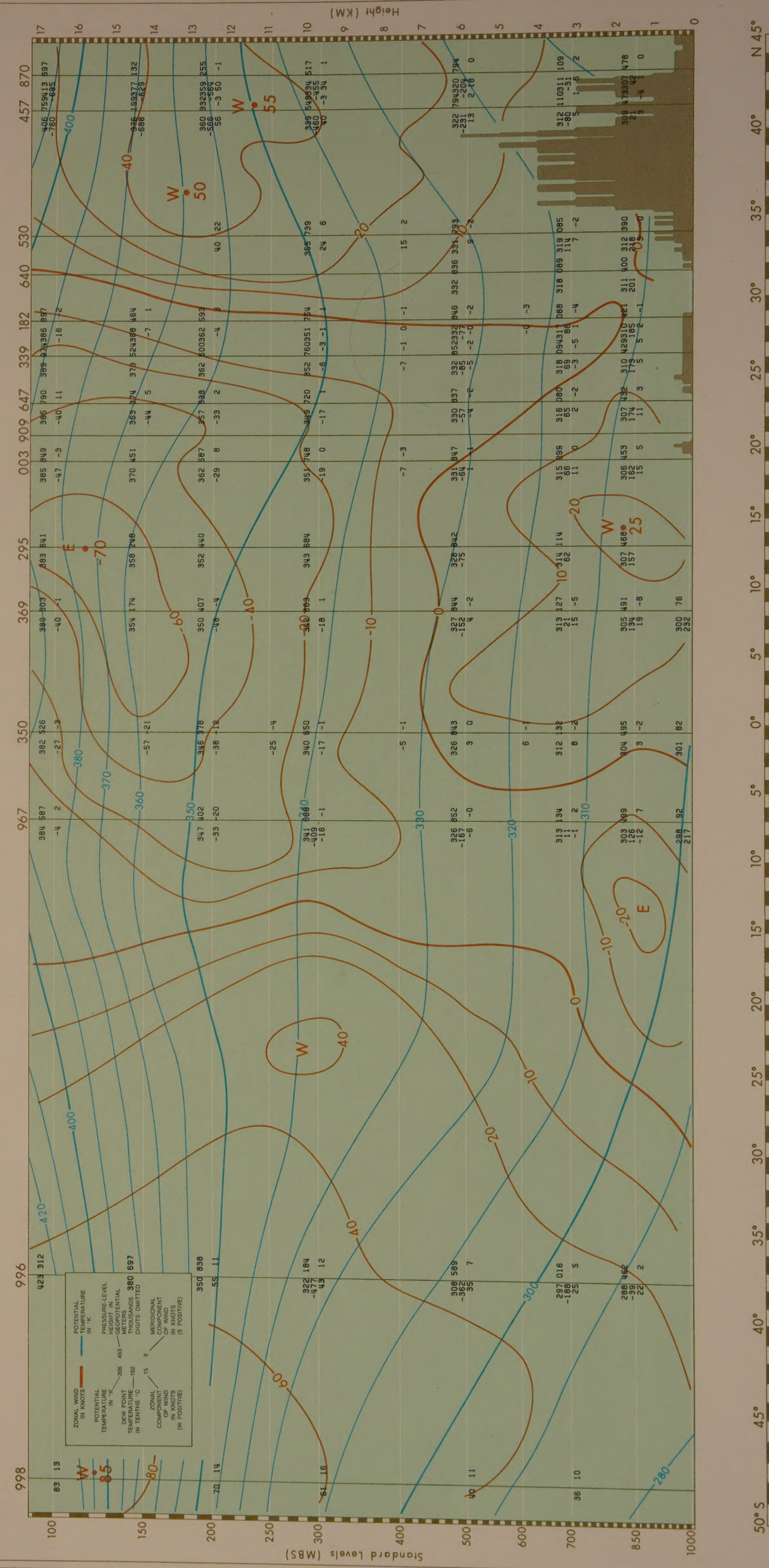
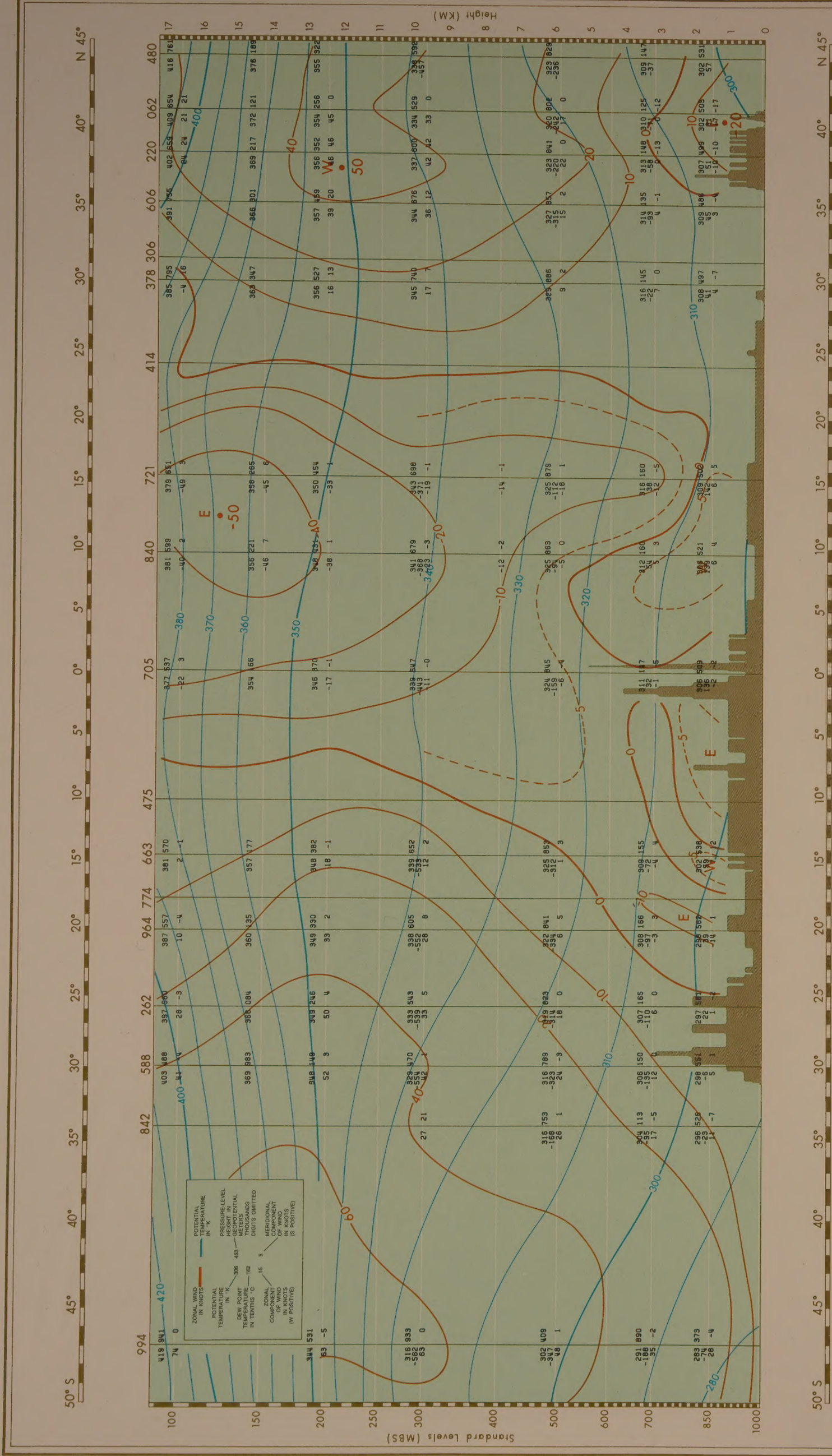


# AUGUST 100 mb Chart 77





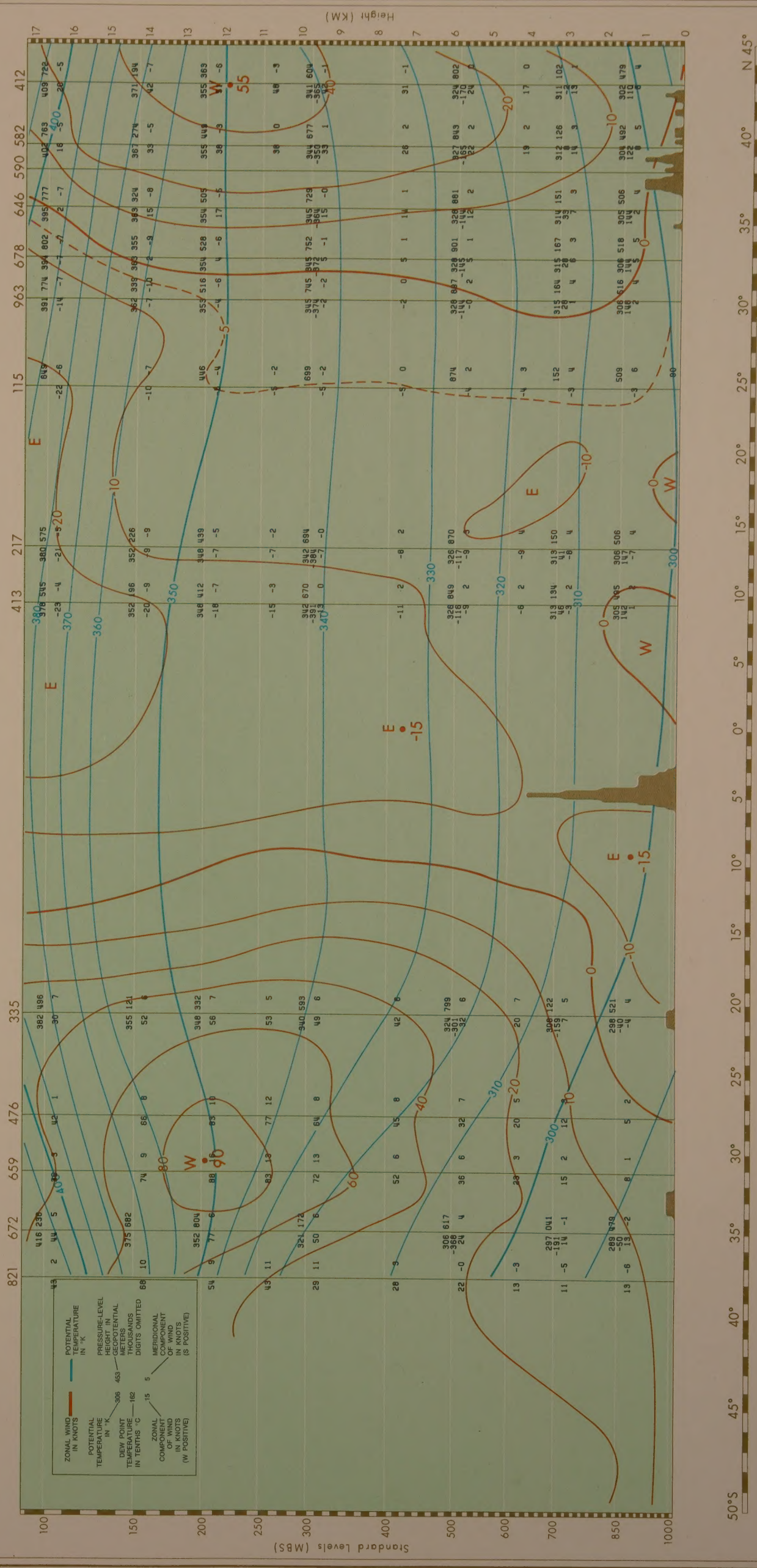
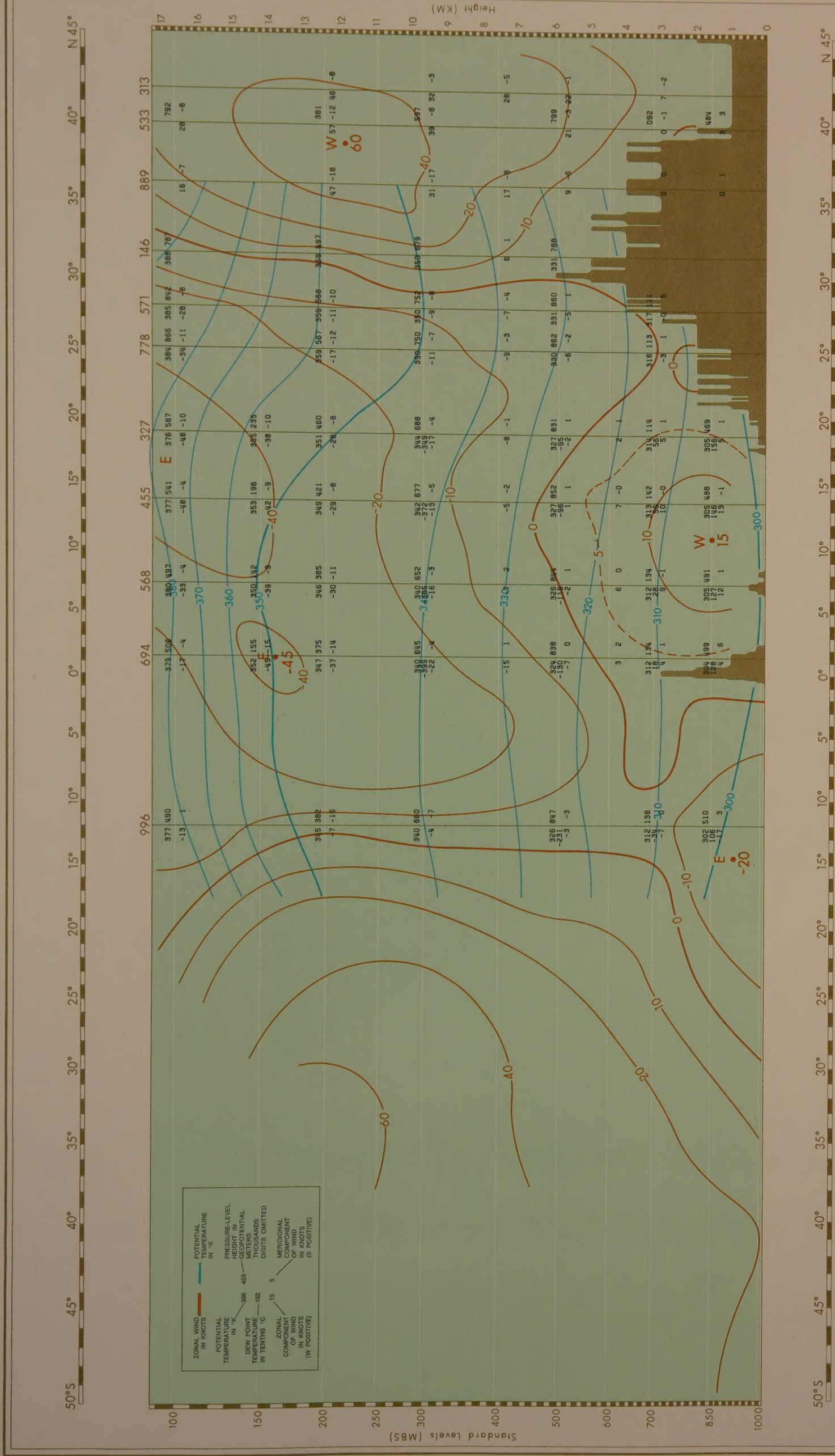
## Chart 78



## Chart 79



## AUGUST 100 E Chart 80

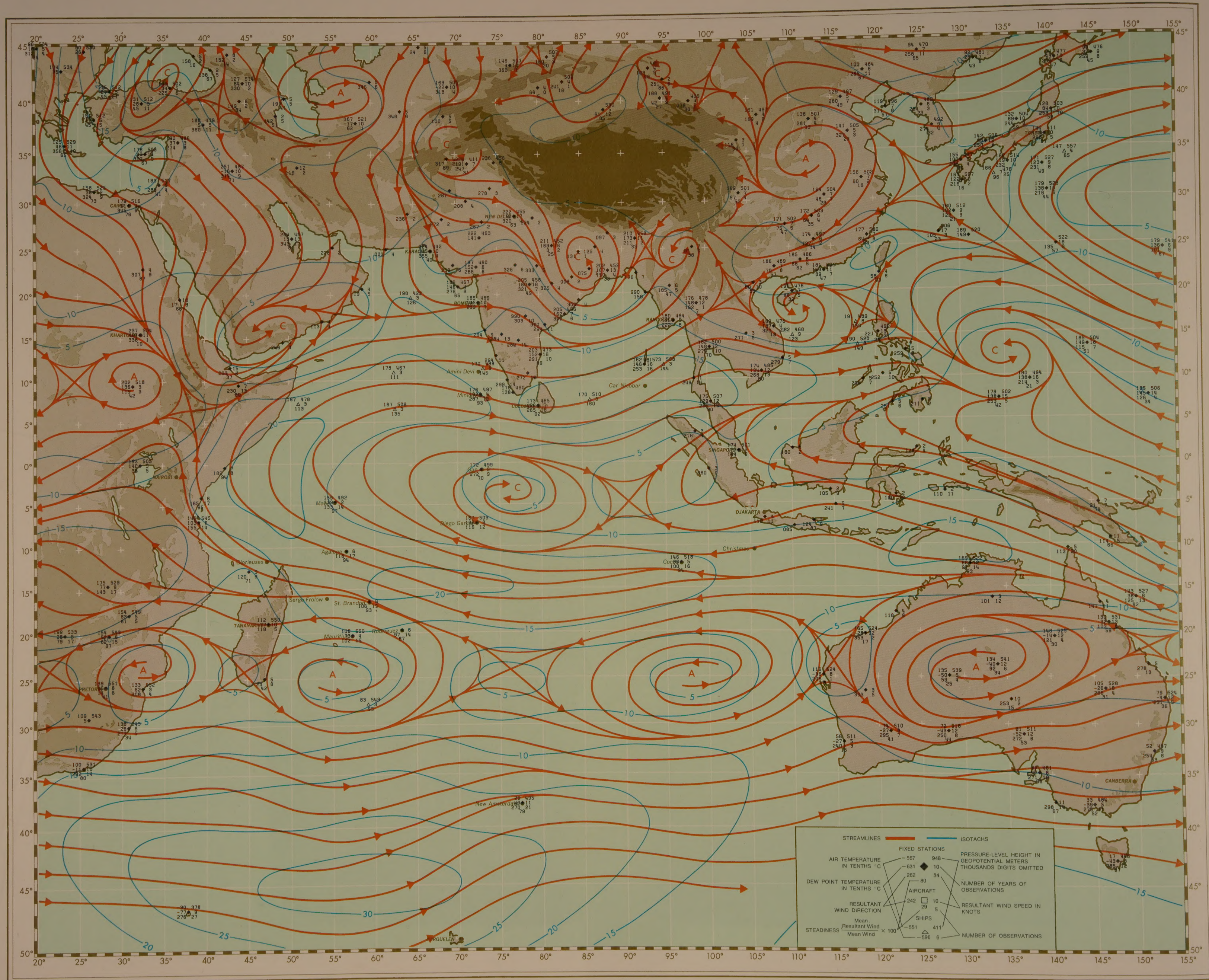


## AUGUST 140 E Chart 81

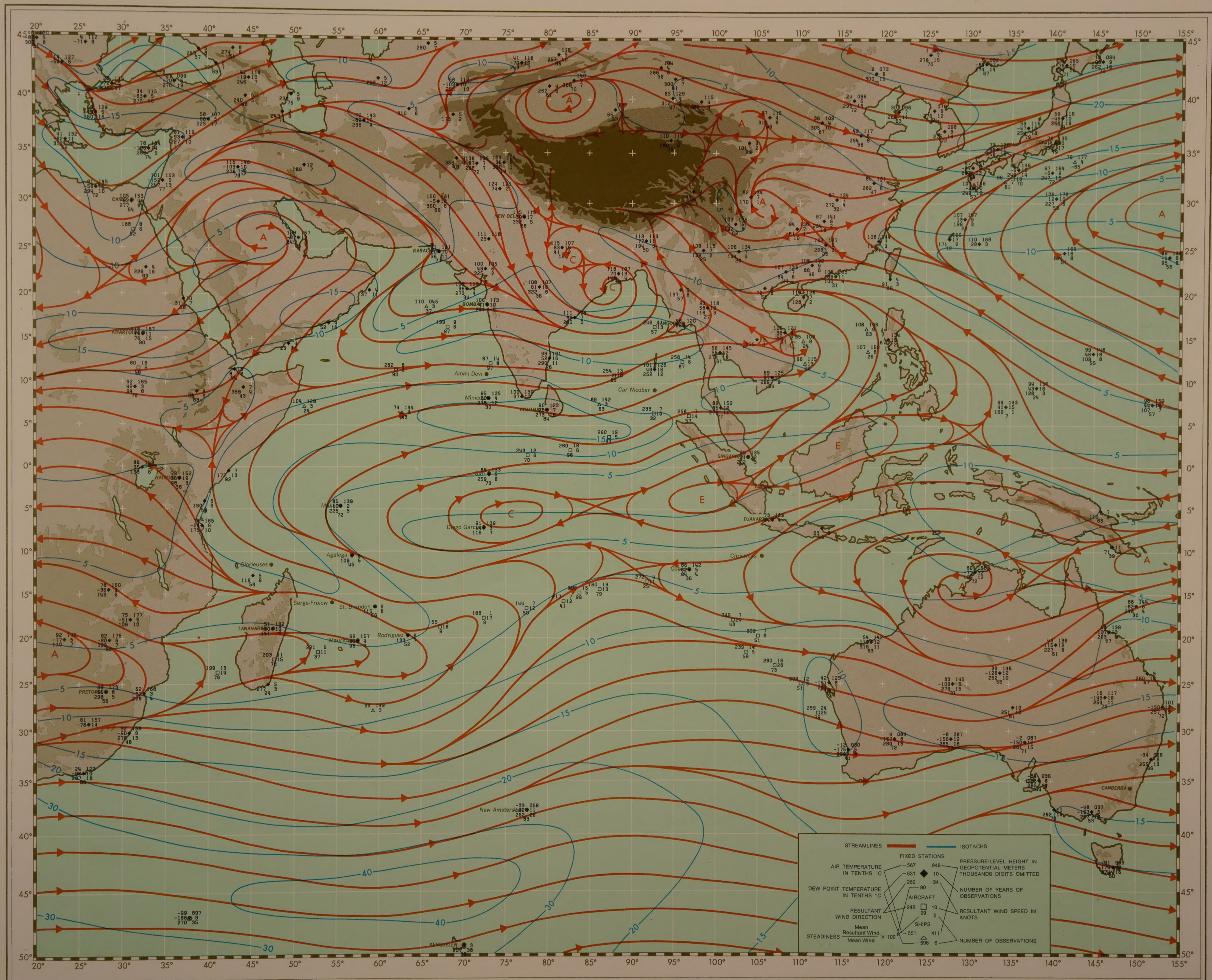


SEPTEMBER 850 mb

Chart 82

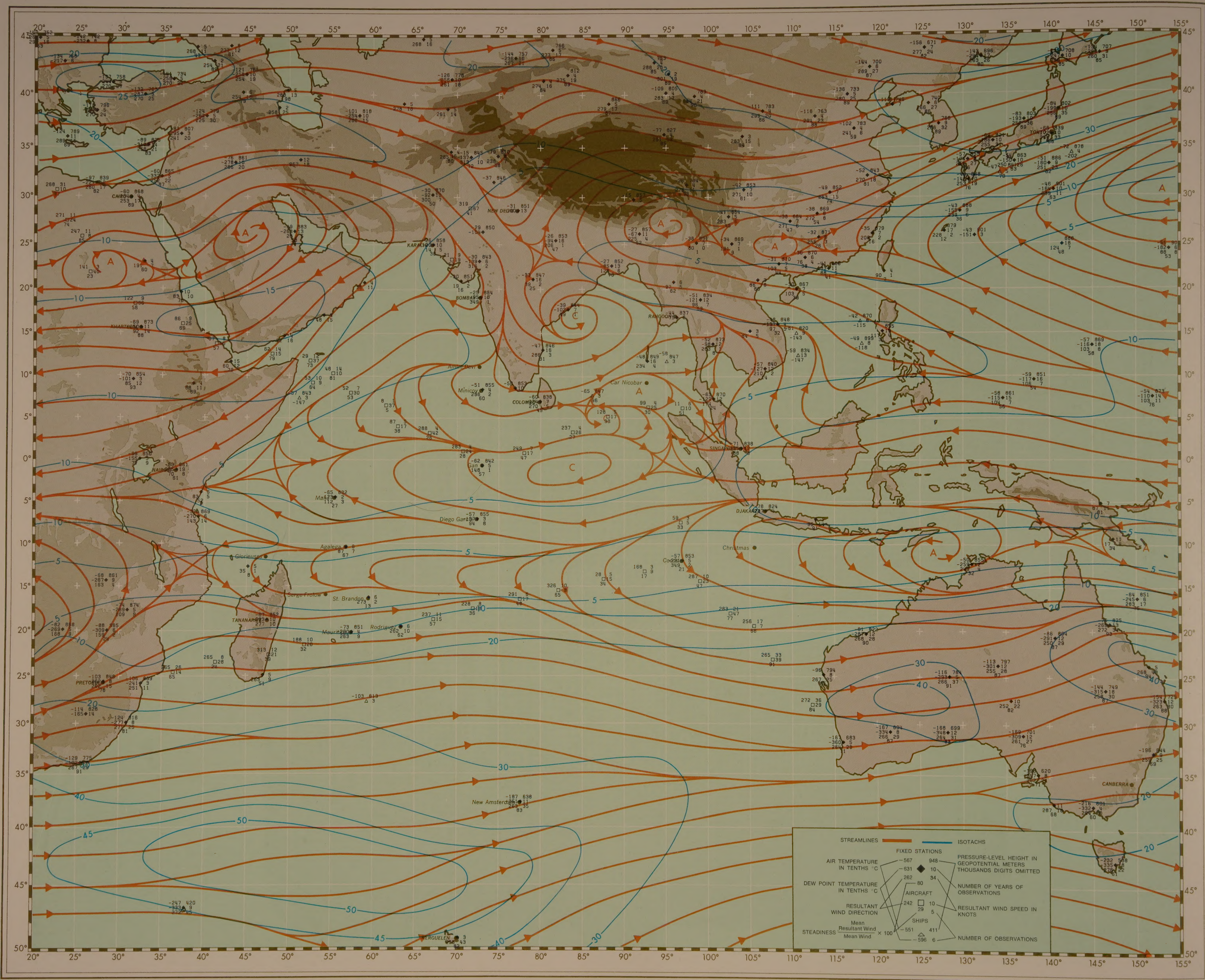




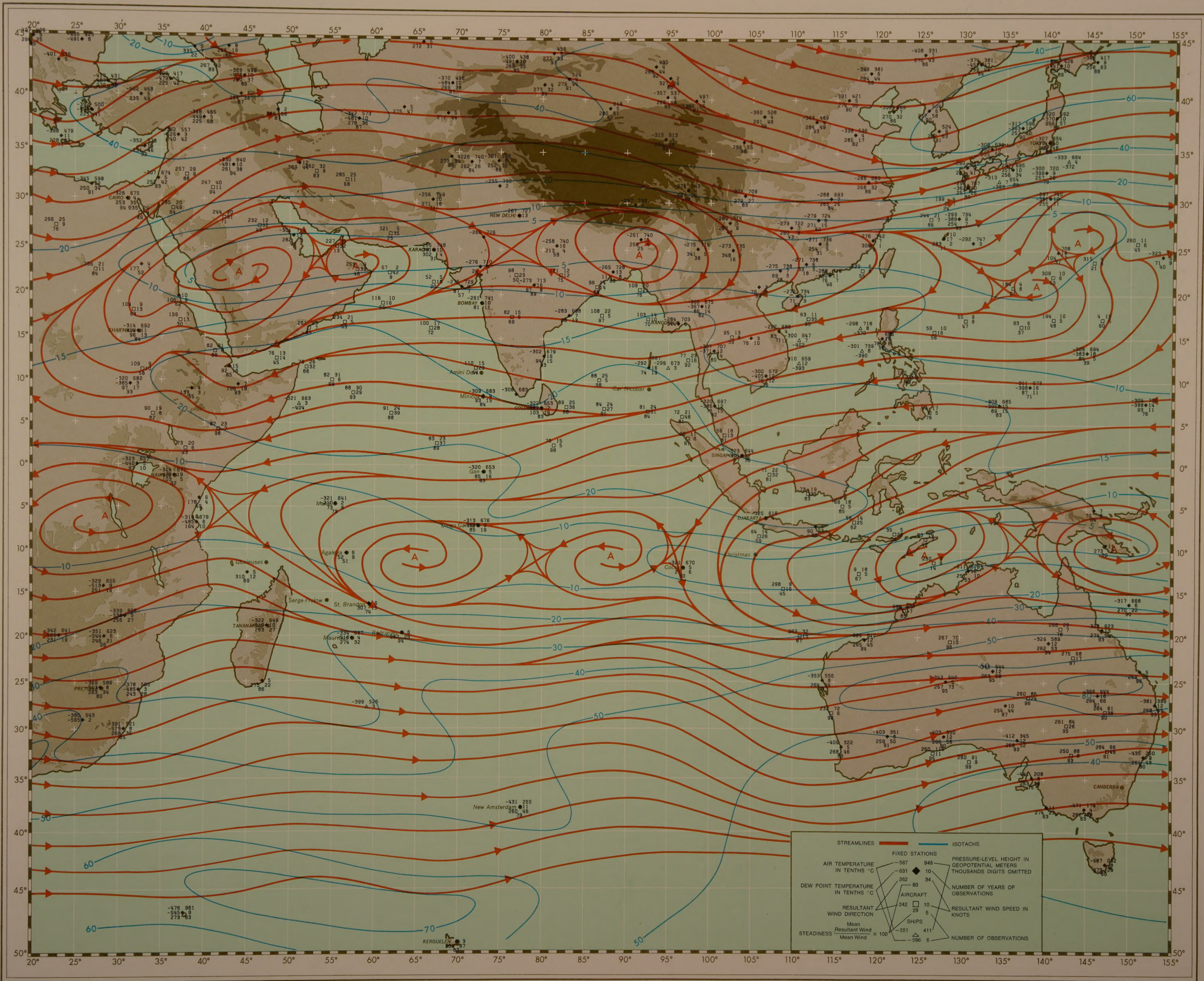




# SEPTEMBER 500 mb Chart 84

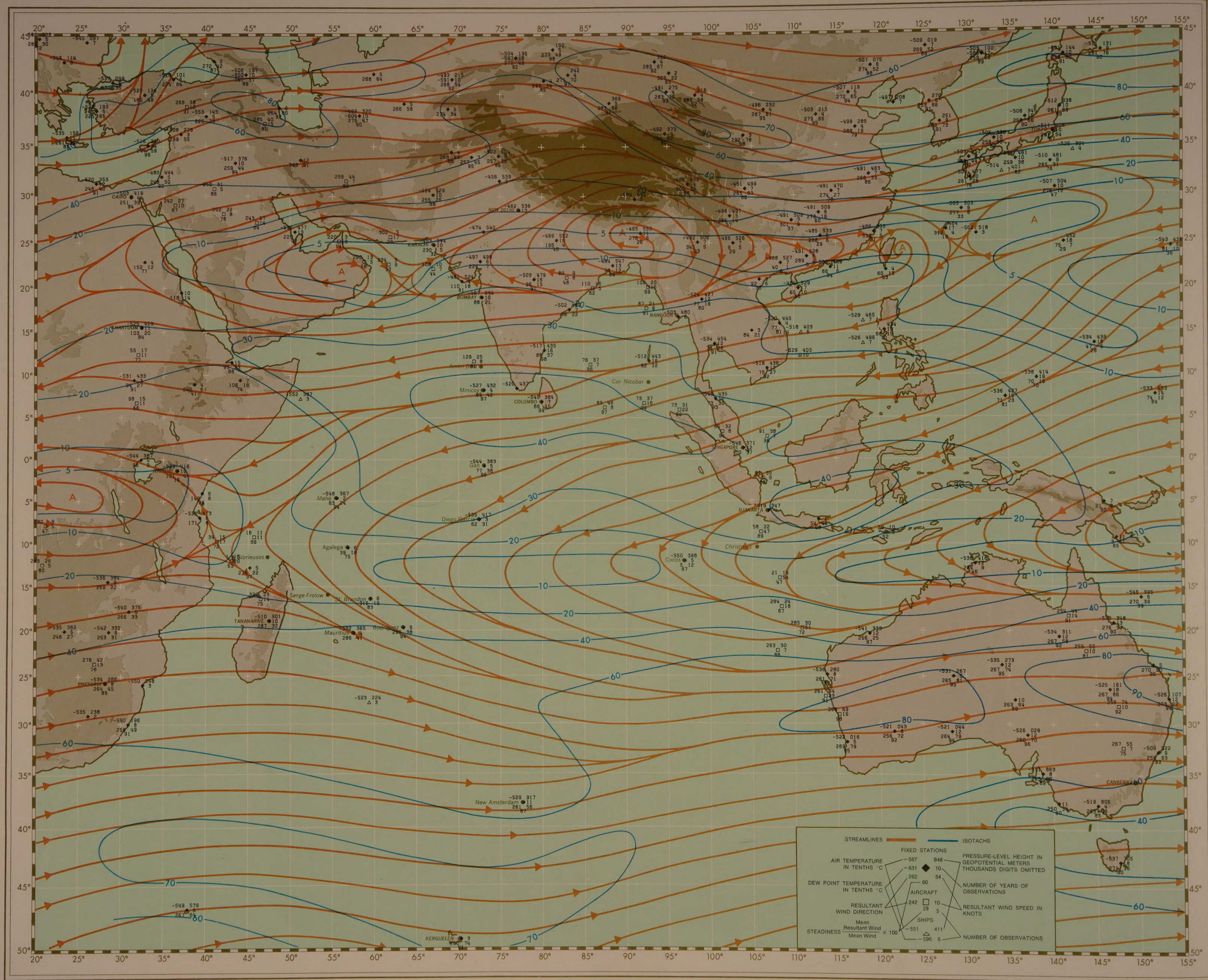




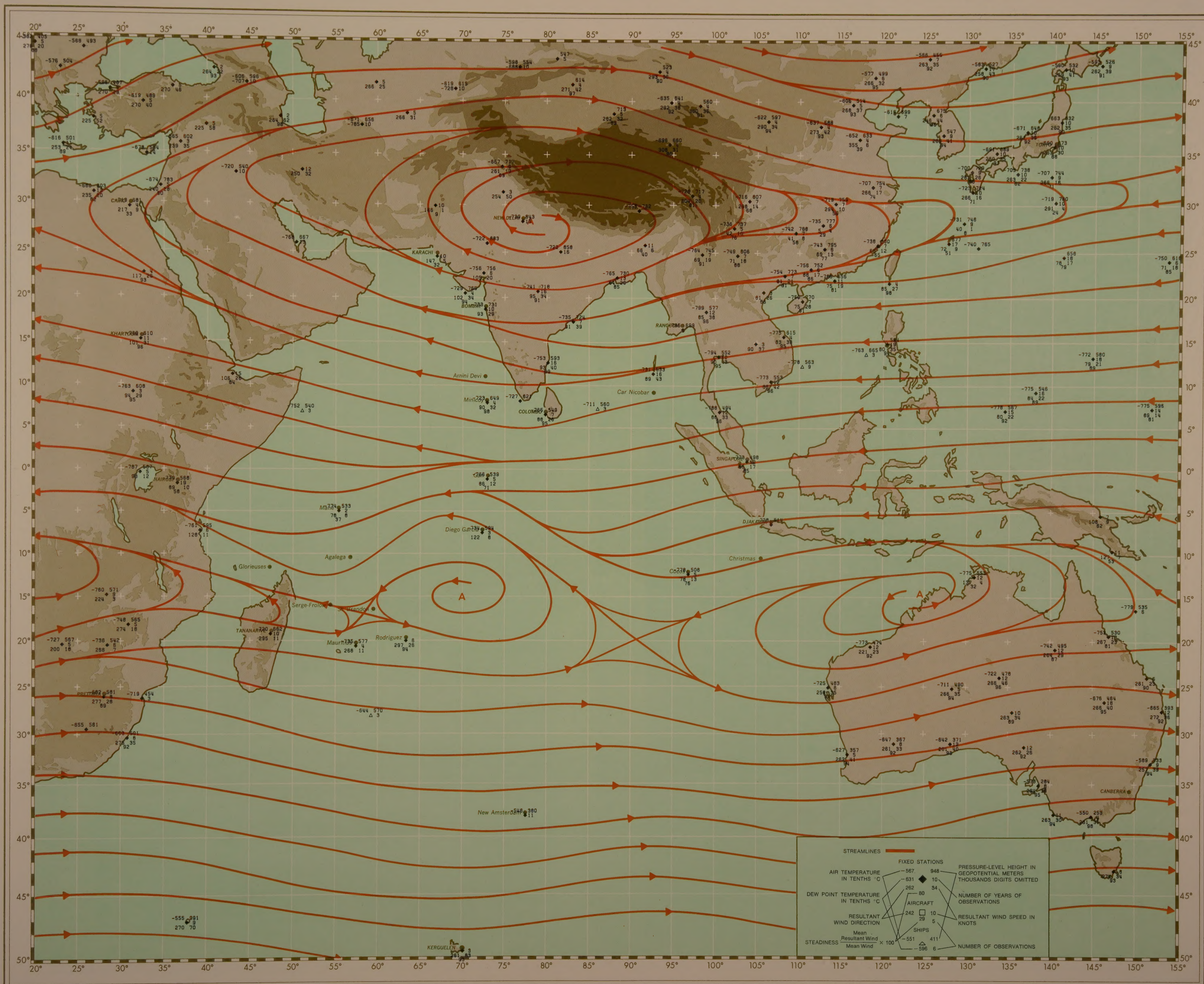




# SEPTEMBER 200 mb Chart 86

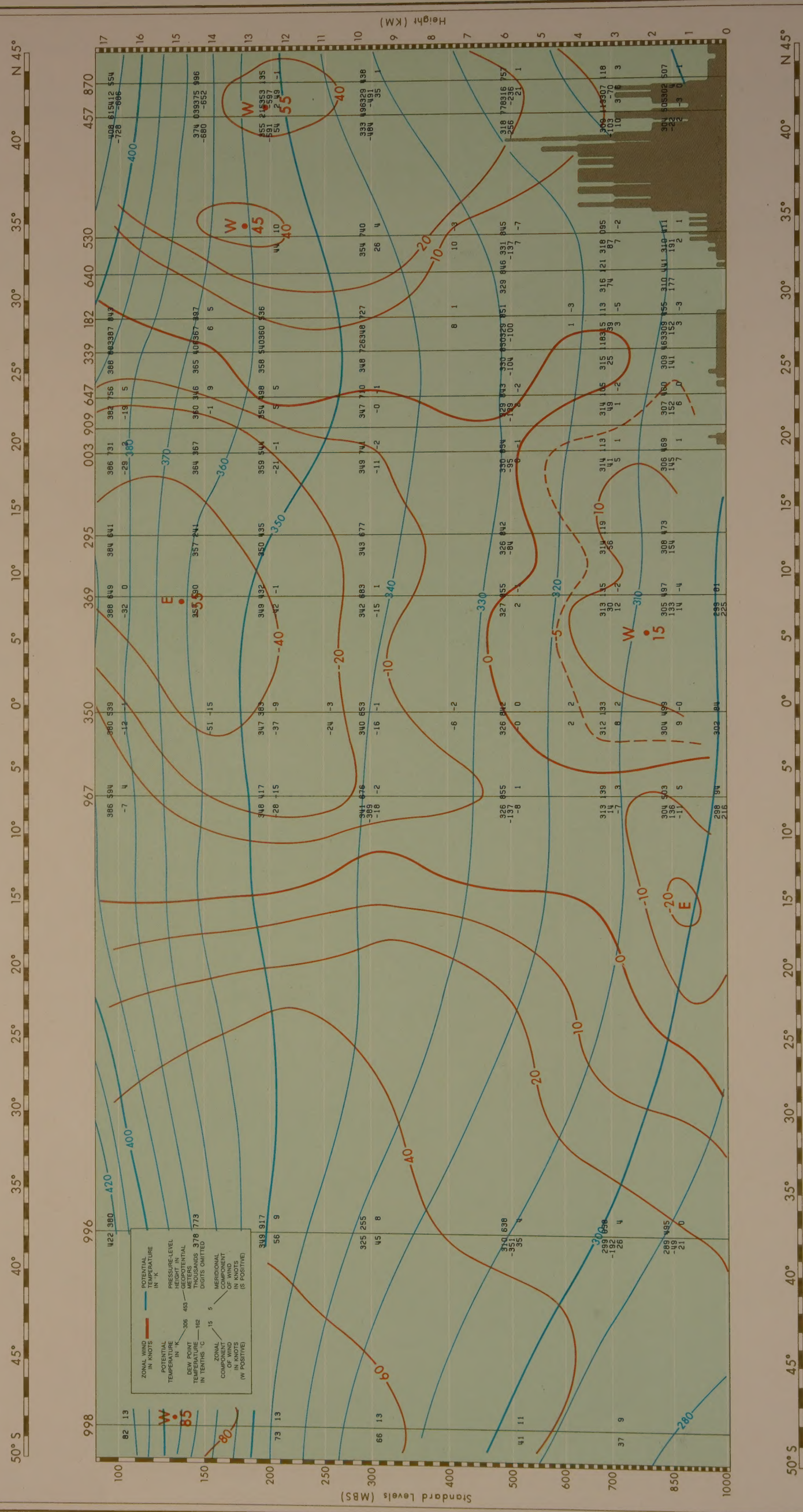
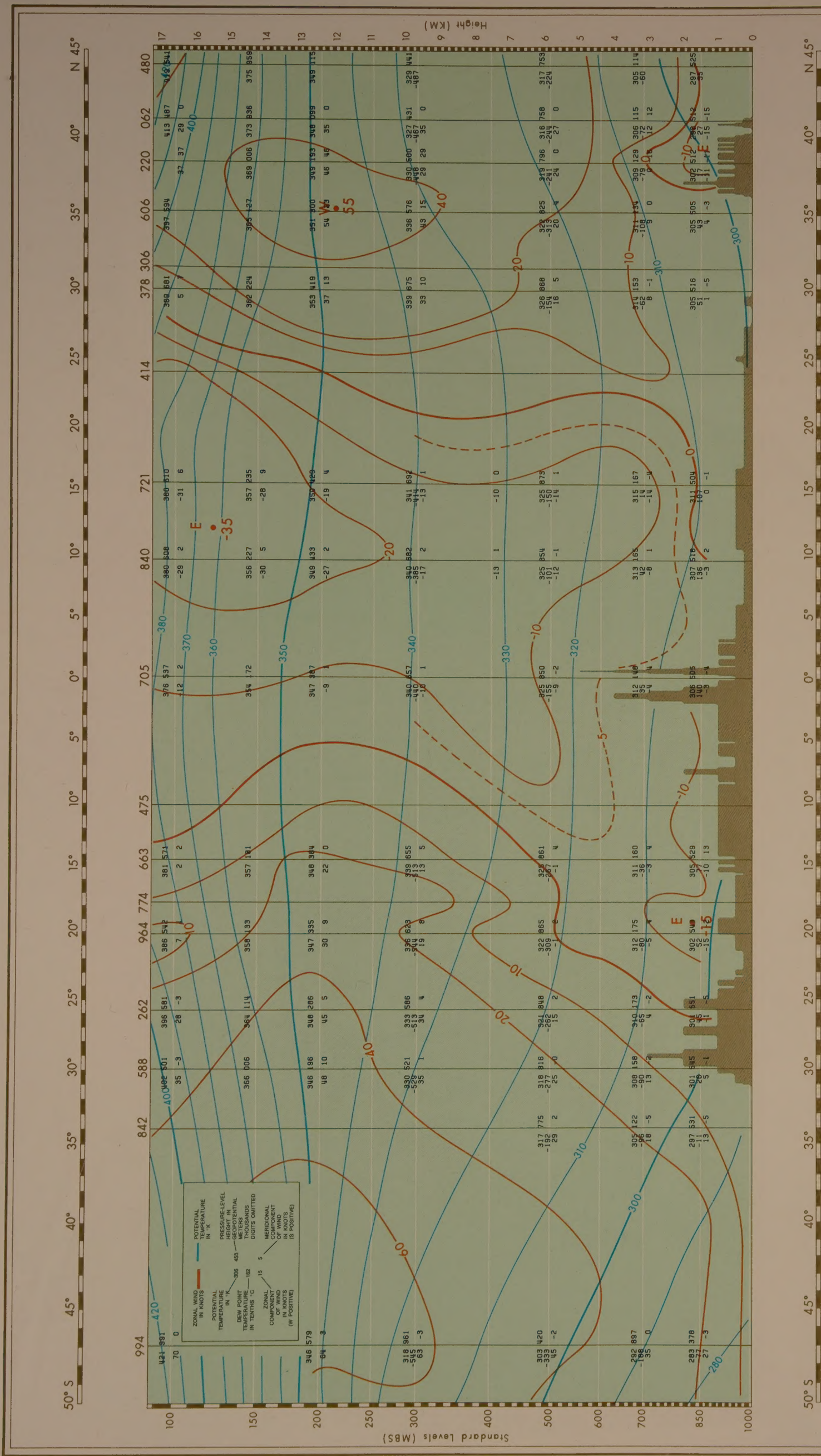




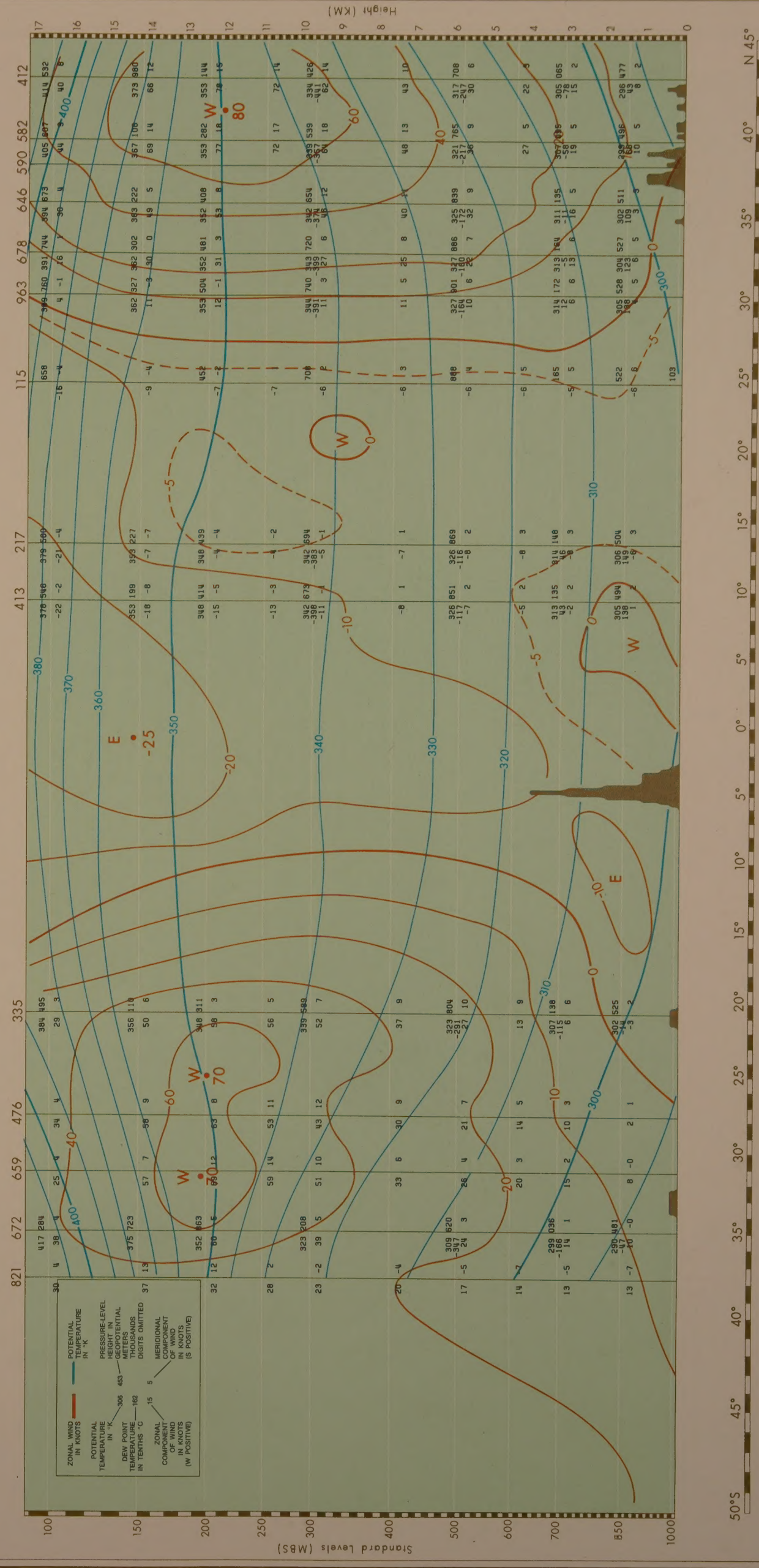
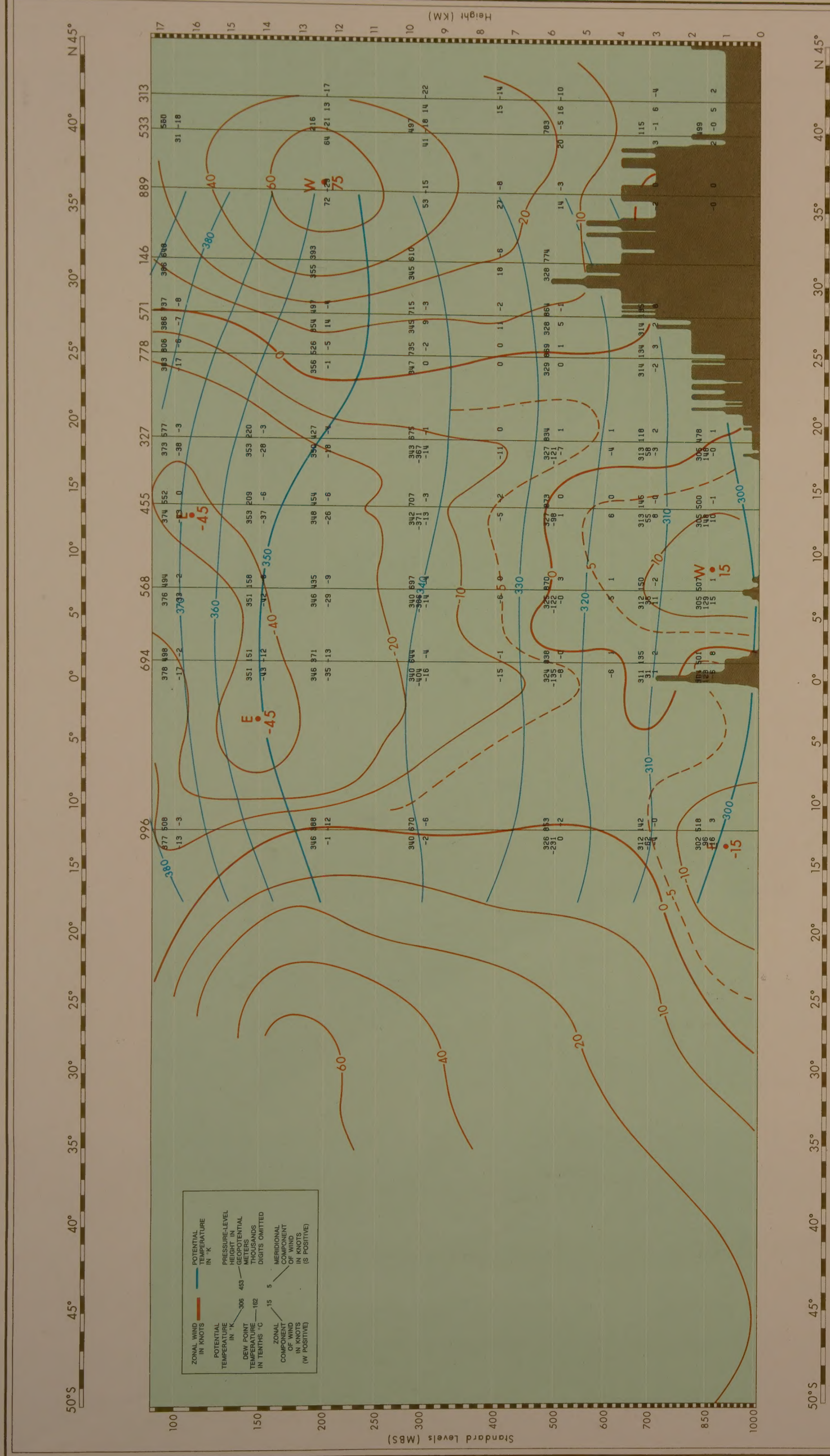




**SEPTEMBER 30 E**

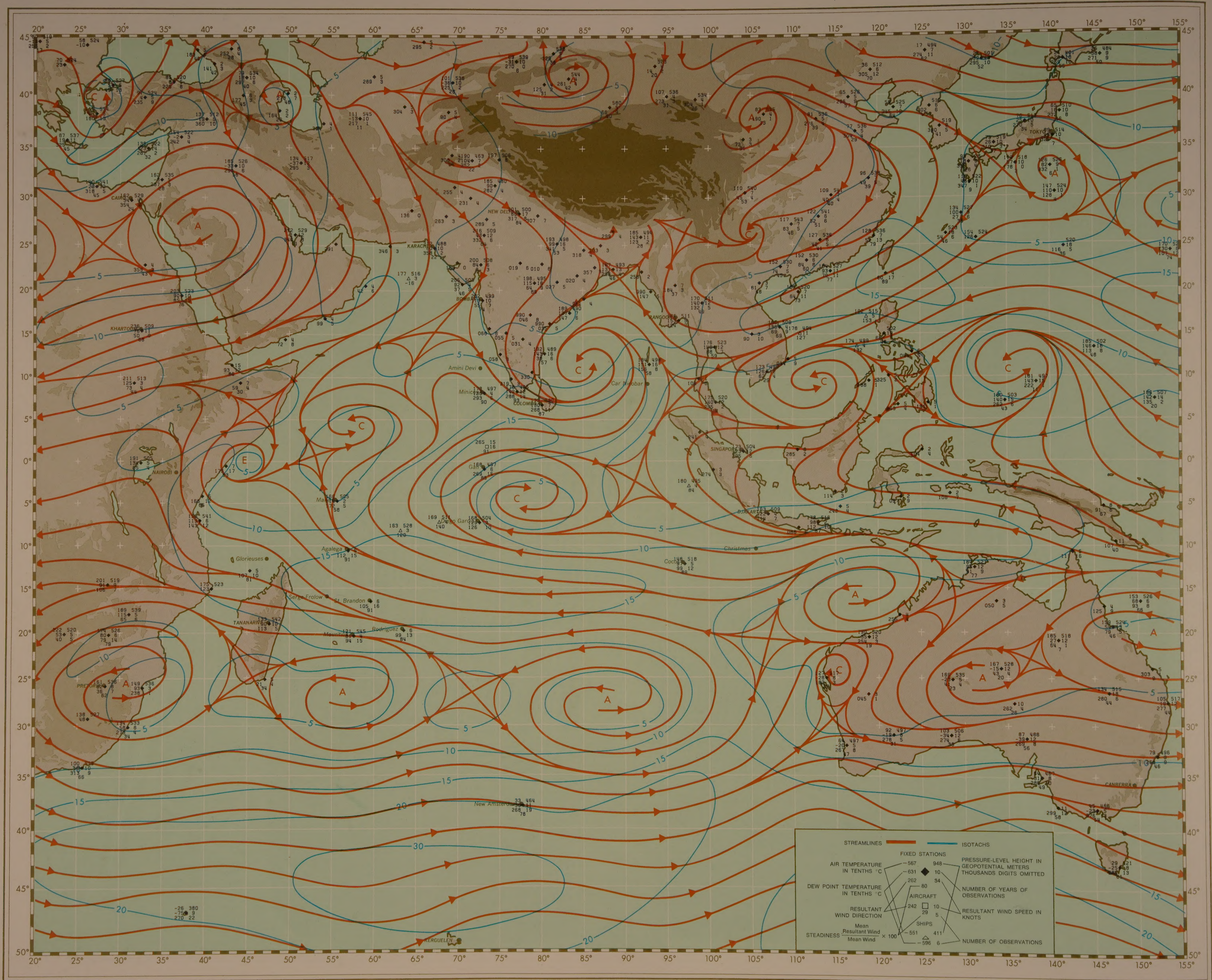




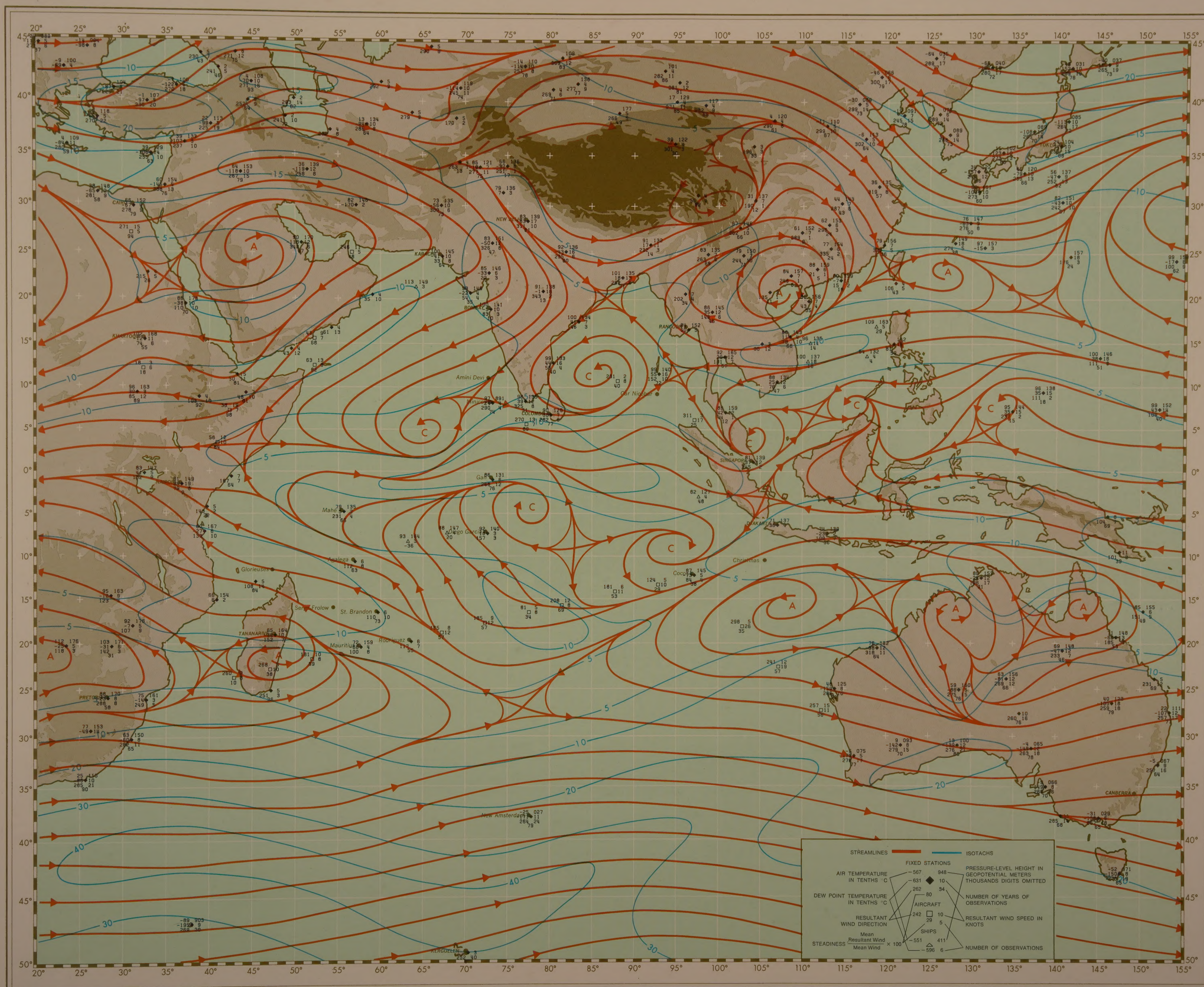




# OCTOBER 850 mb Chart 92







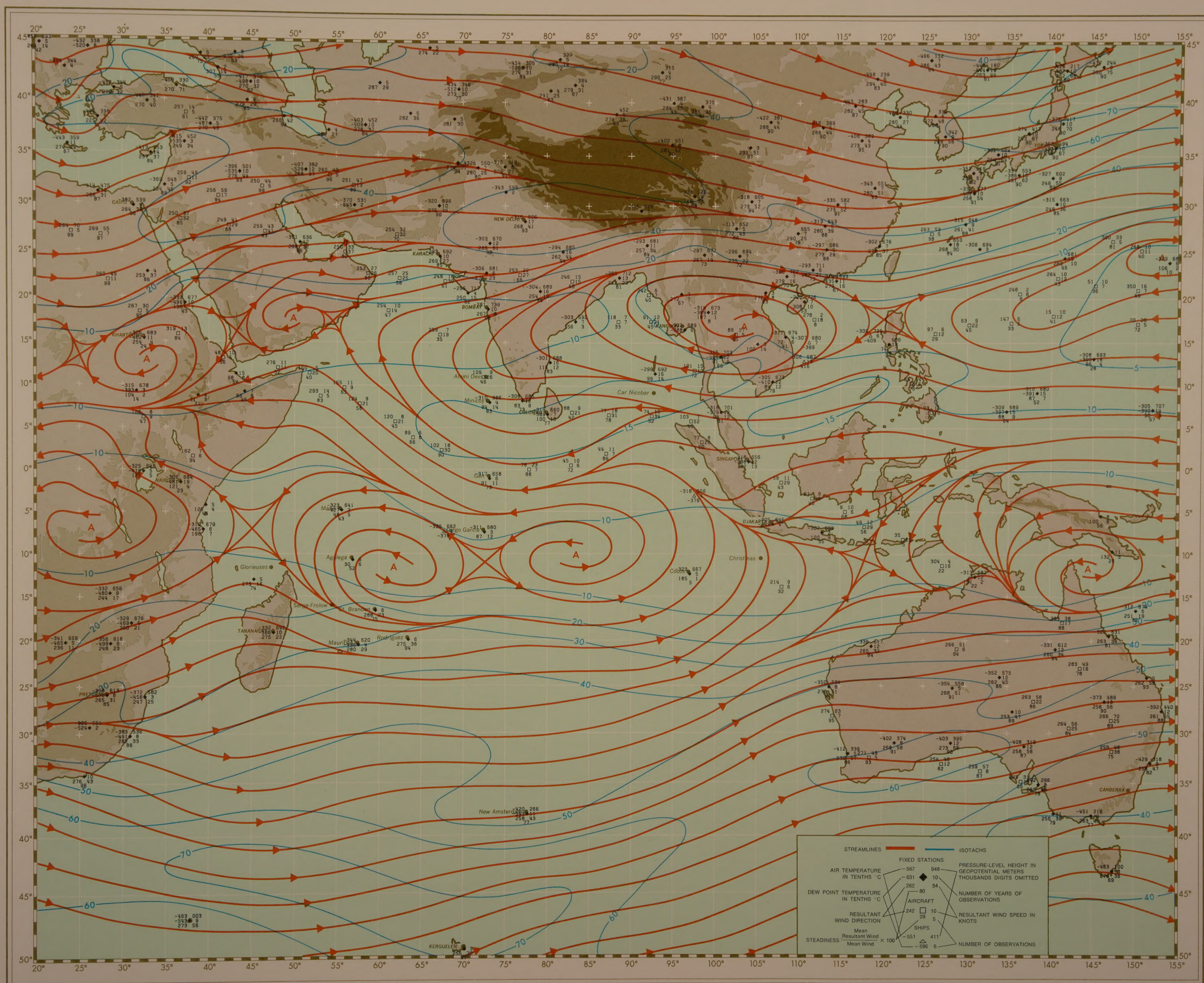


OCTOBER 500 mb Chart 94



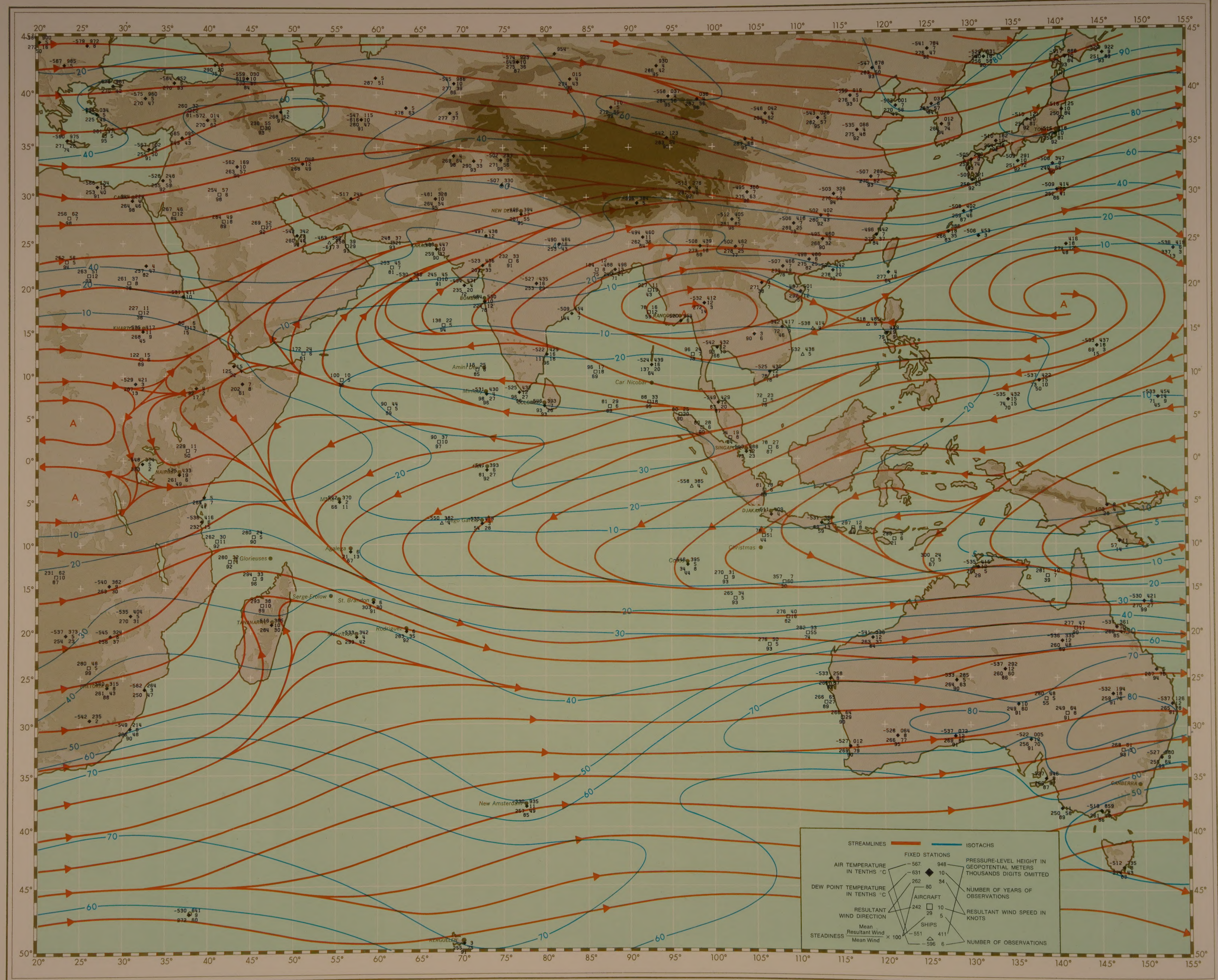


# OCTOBER 300 mb Chart 95

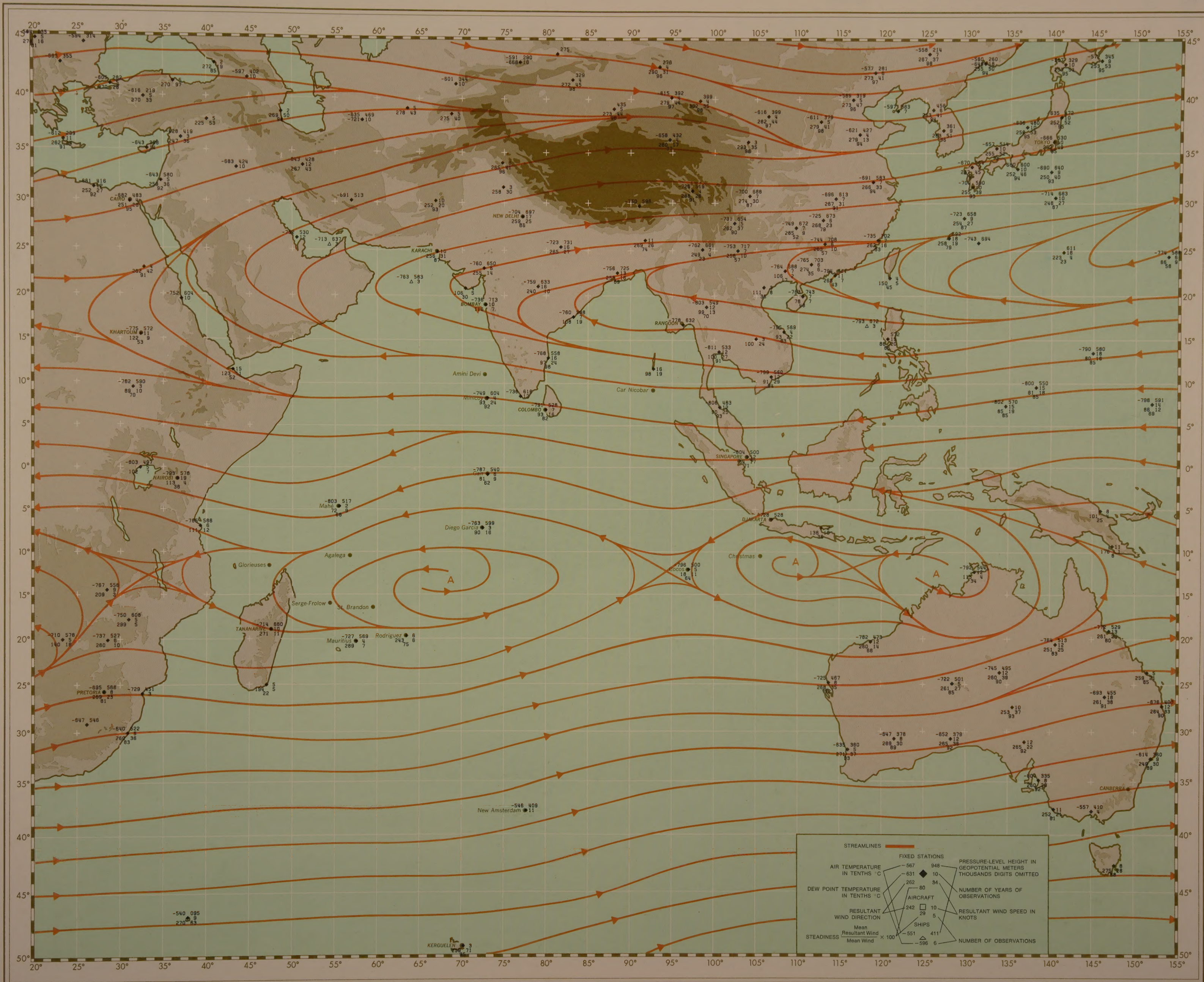




# OCTOBER 200 mb Chart 96

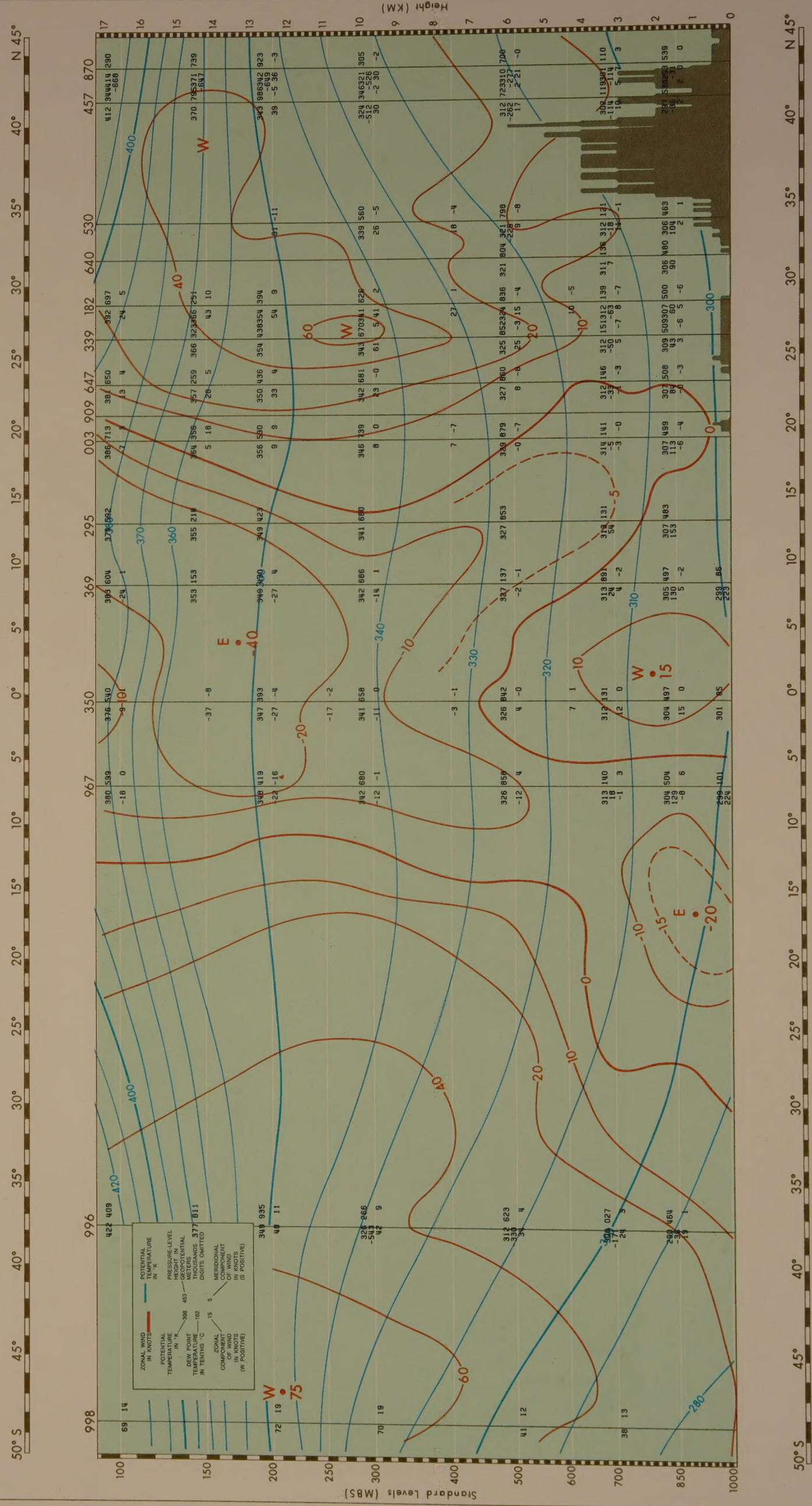
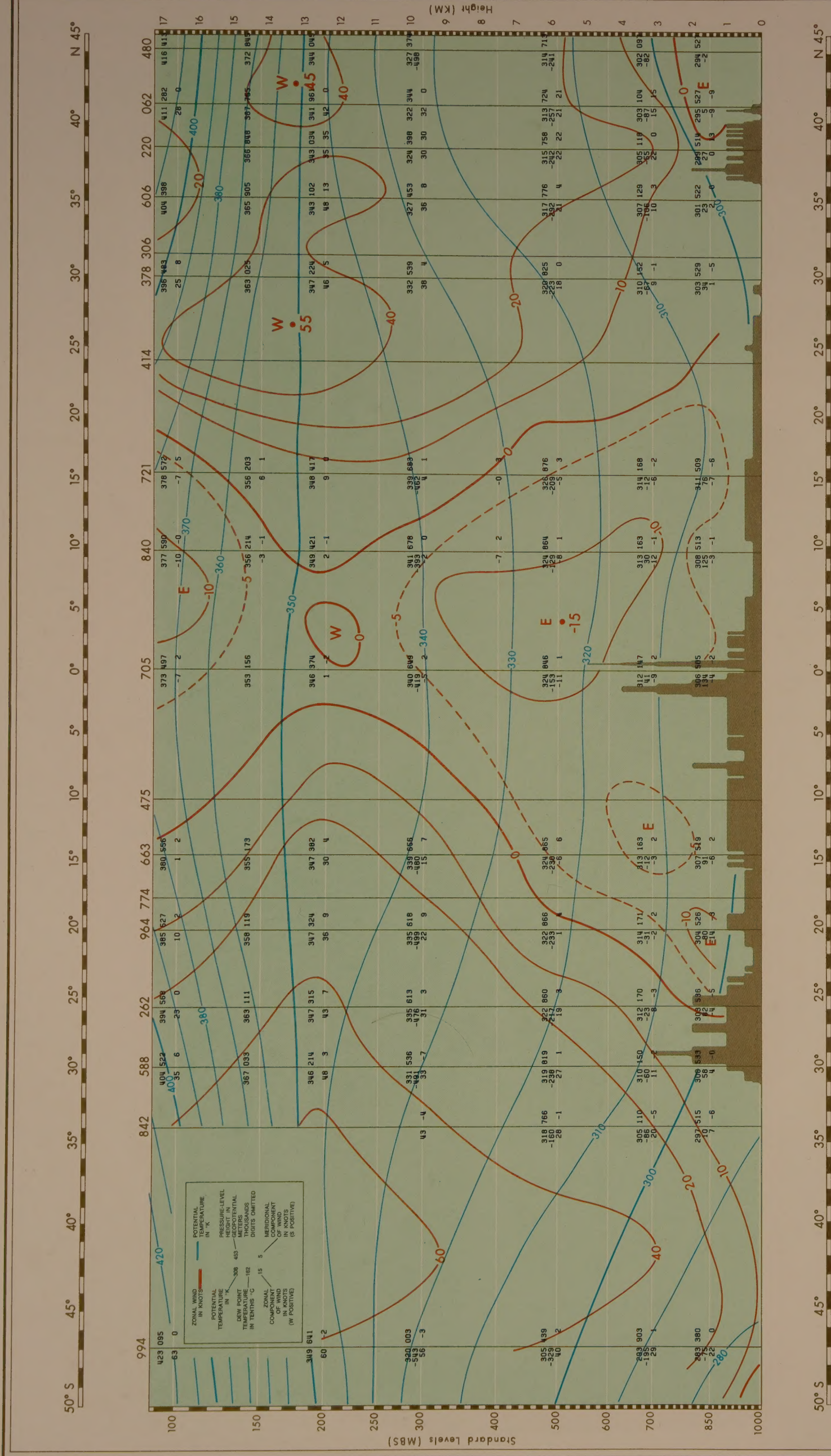




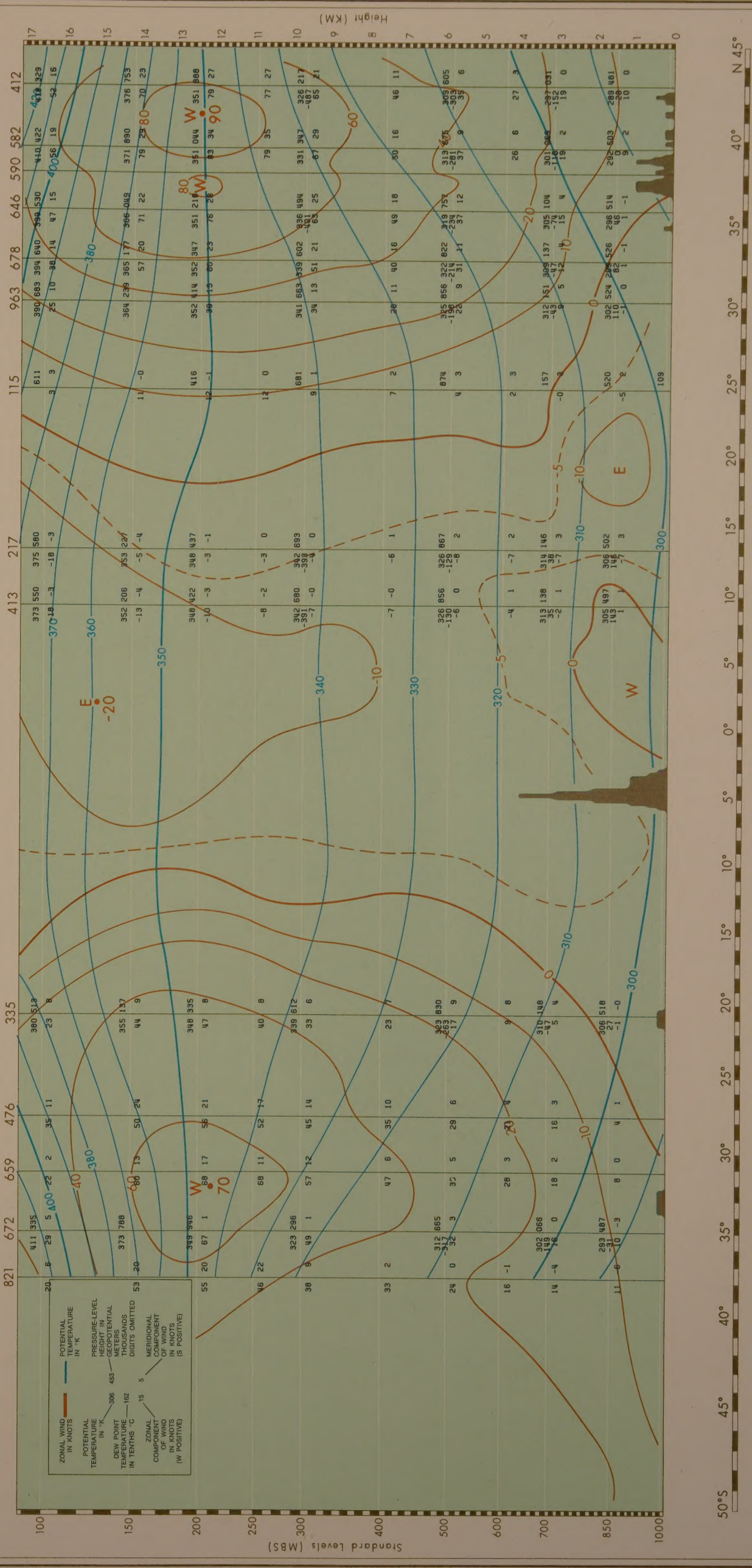
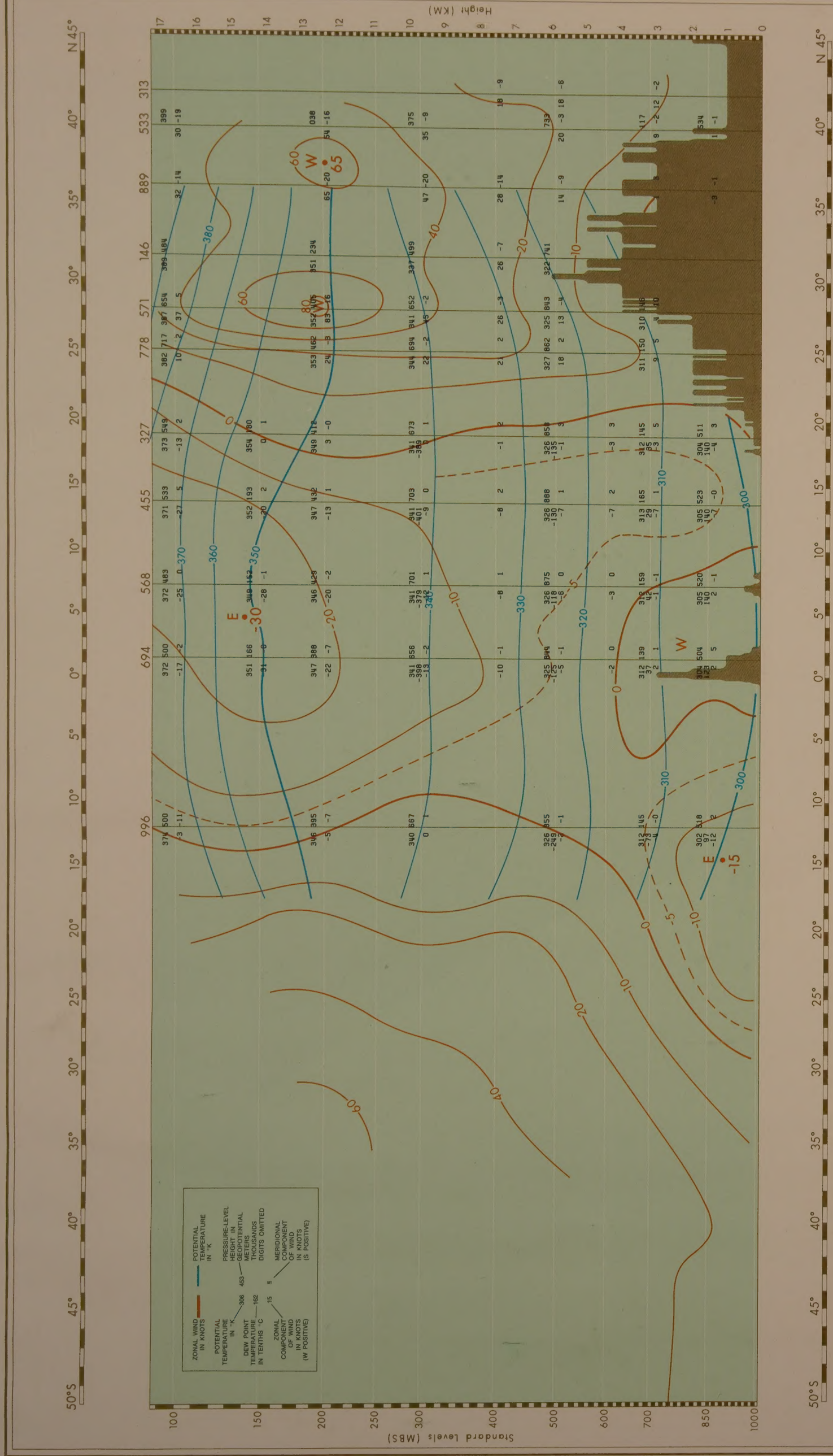




## OCTOBER 30 E Chart 98

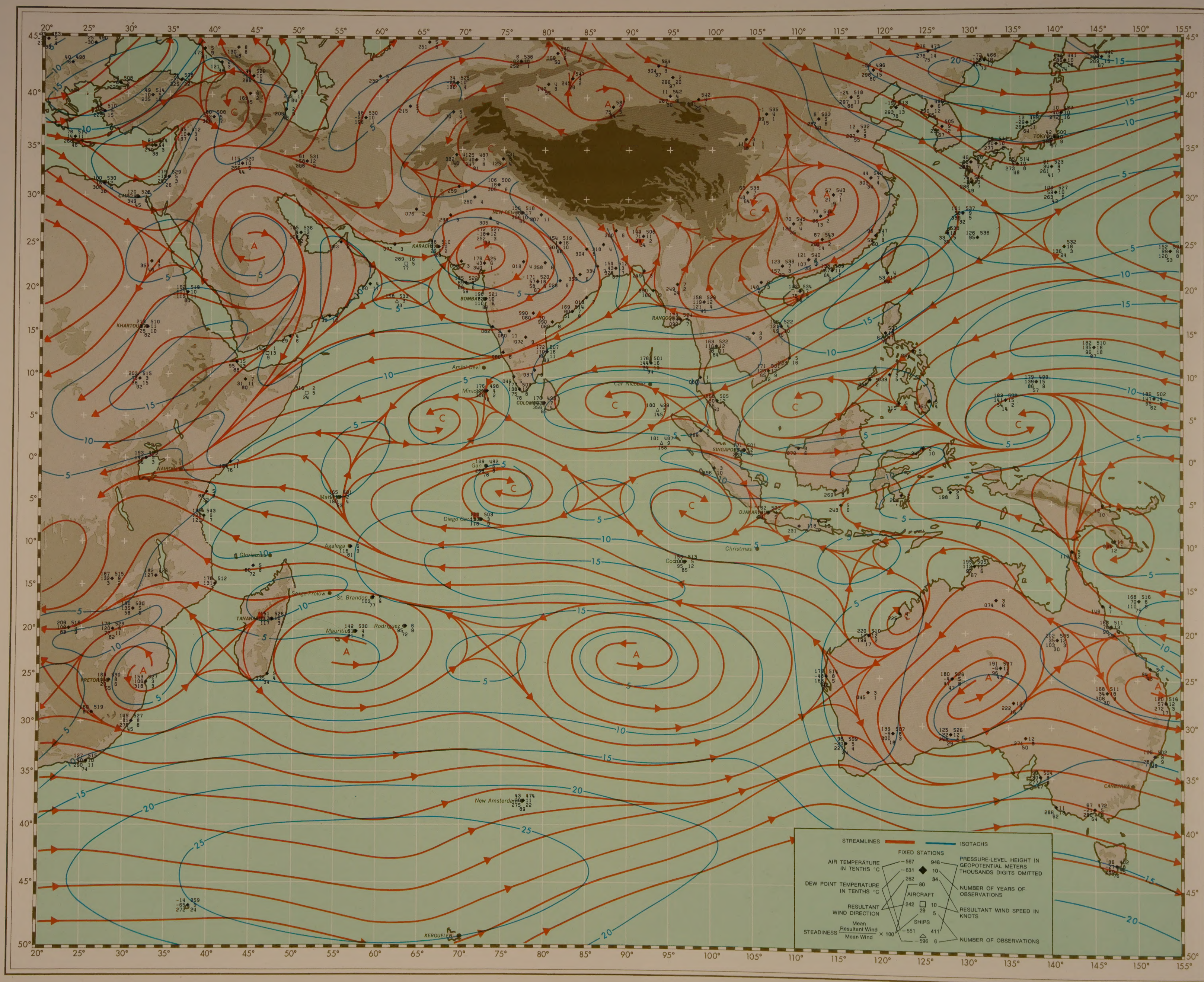






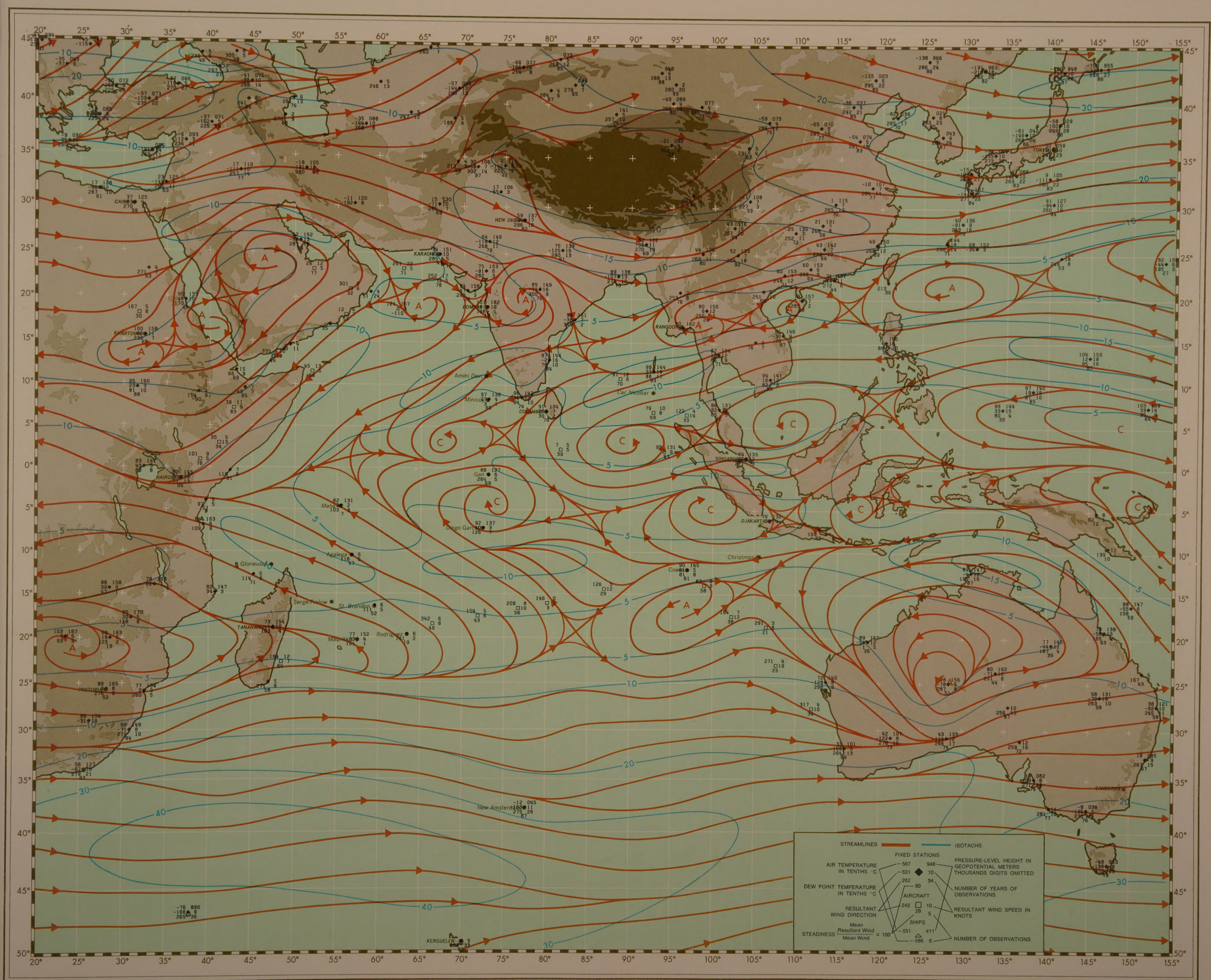


# NOVEMBER 850 mb Chart 102





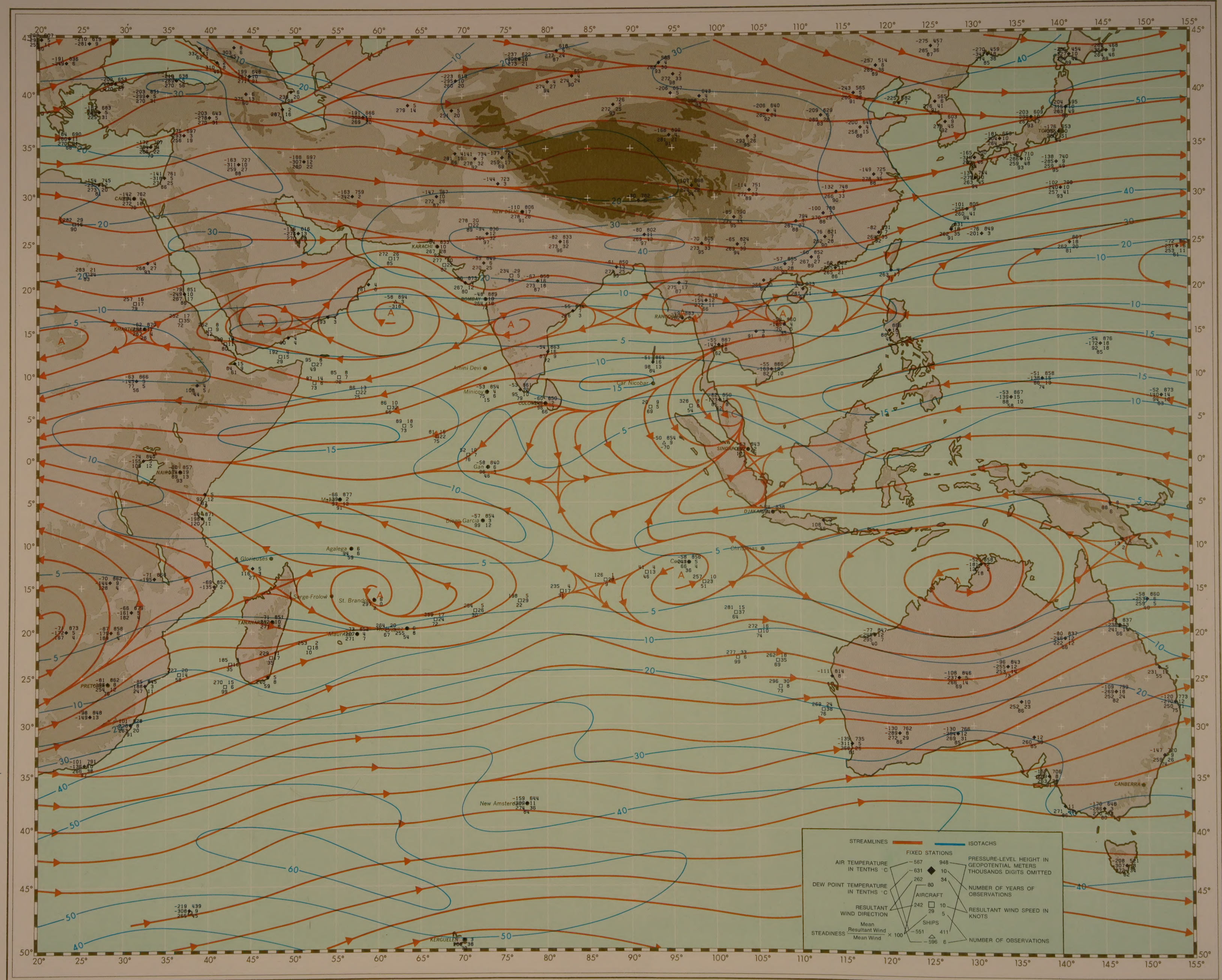
# NOVEMBER 700 mb Chart 103



|                                    |                                 |
|------------------------------------|---------------------------------|
| STREAMLINES                        | ISOTACHS                        |
| AIR TEMPERATURE IN TENTHS °C       | FIXED STATIONS                  |
| DEW POINT TEMPERATURE IN TENTHS °C | 567 948                         |
| RESULTANT WIND DIRECTION           | 631 10                          |
| Mean Resultant Wind                | 262 34                          |
| Mean Wind                          | 242 10                          |
| STEADINESS                         | 29 5                            |
|                                    | 551 411                         |
|                                    | 596 6                           |
|                                    | NUMBER OF YEARS OF OBSERVATIONS |
|                                    | RESULTANT WIND SPEED IN KNOTS   |
|                                    | NUMBER OF OBSERVATIONS          |

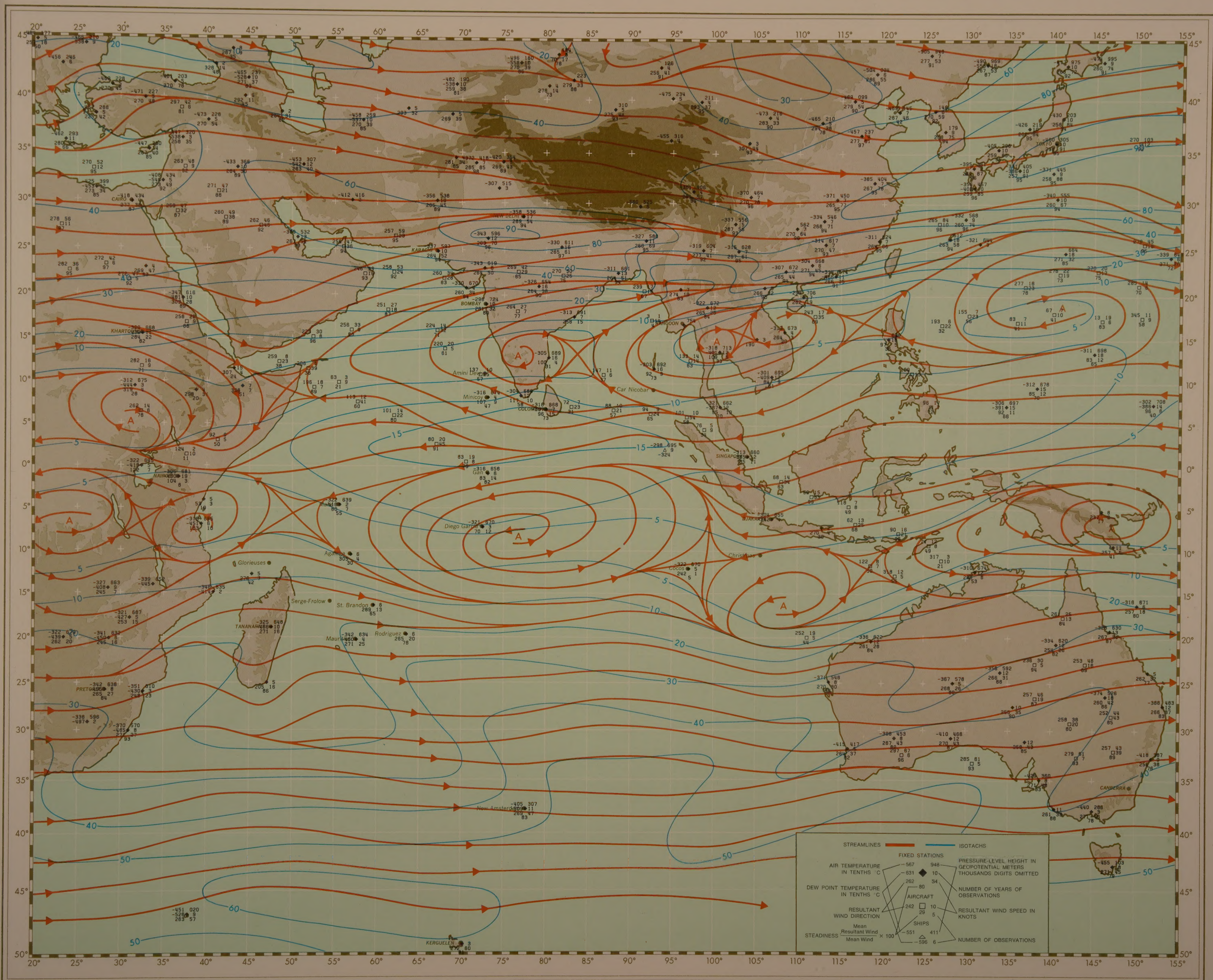


# NOVEMBER 500 mb Chart 104



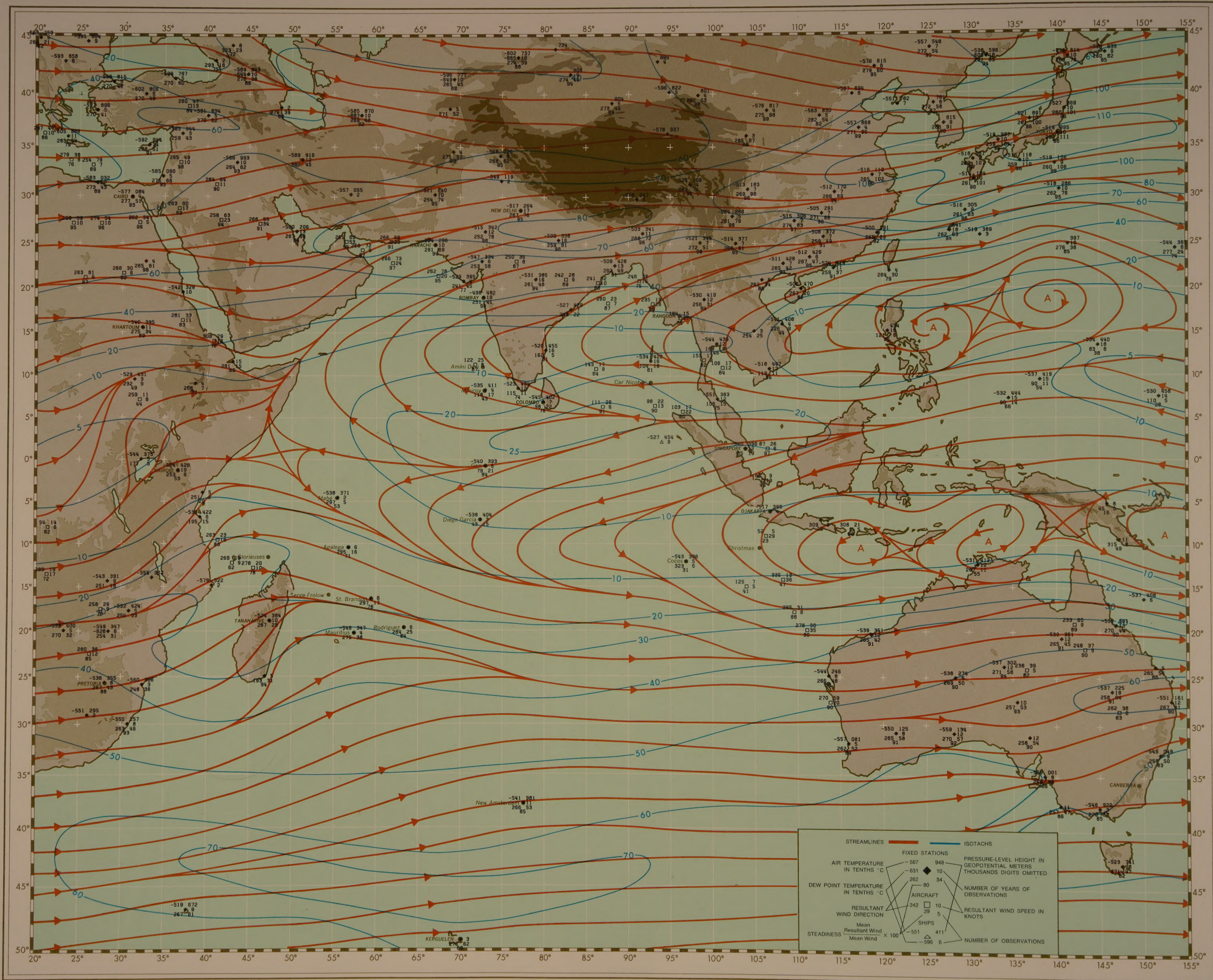


# NOVEMBER 300 mb Chart 105



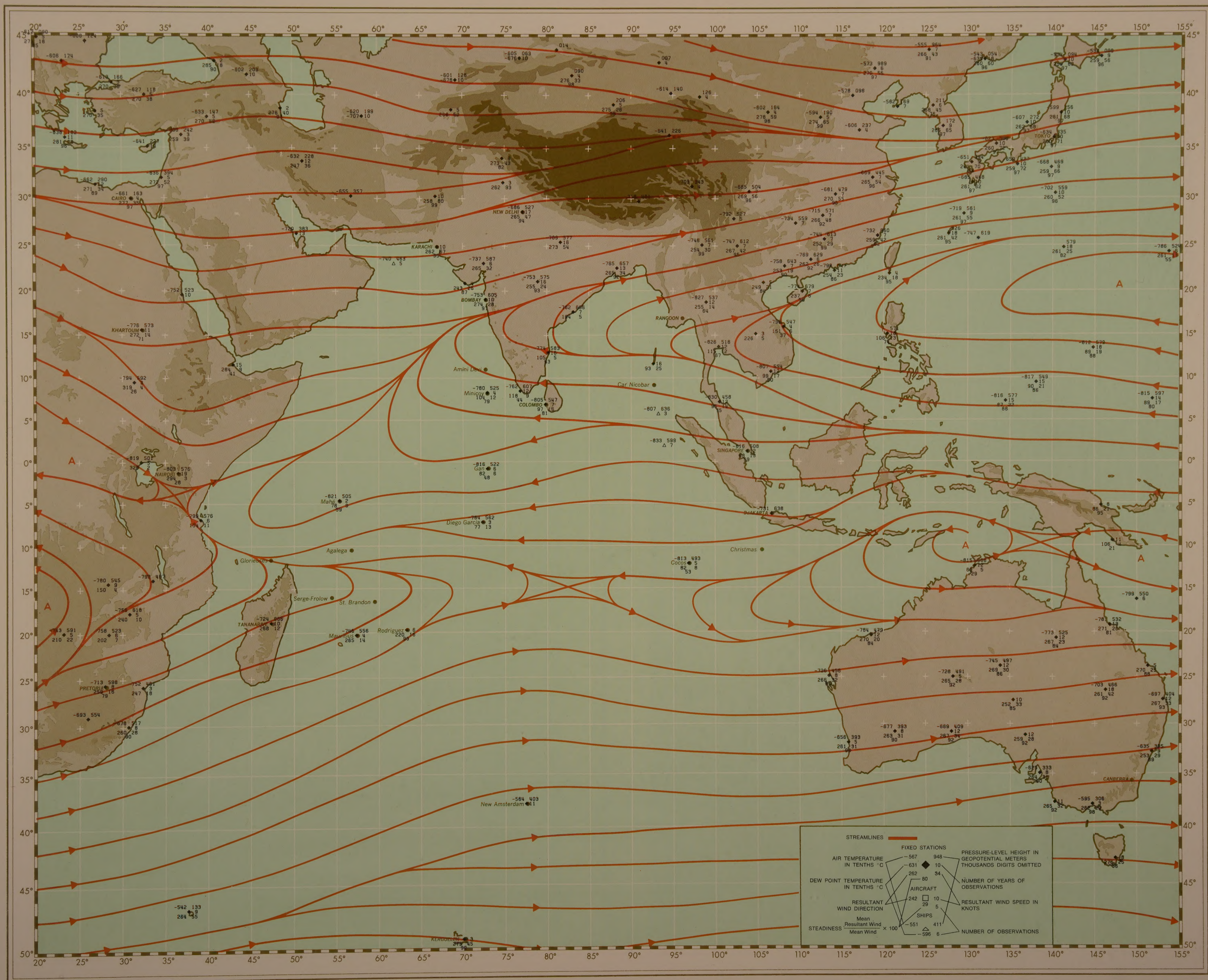


# NOVEMBER 200 mb Chart 106



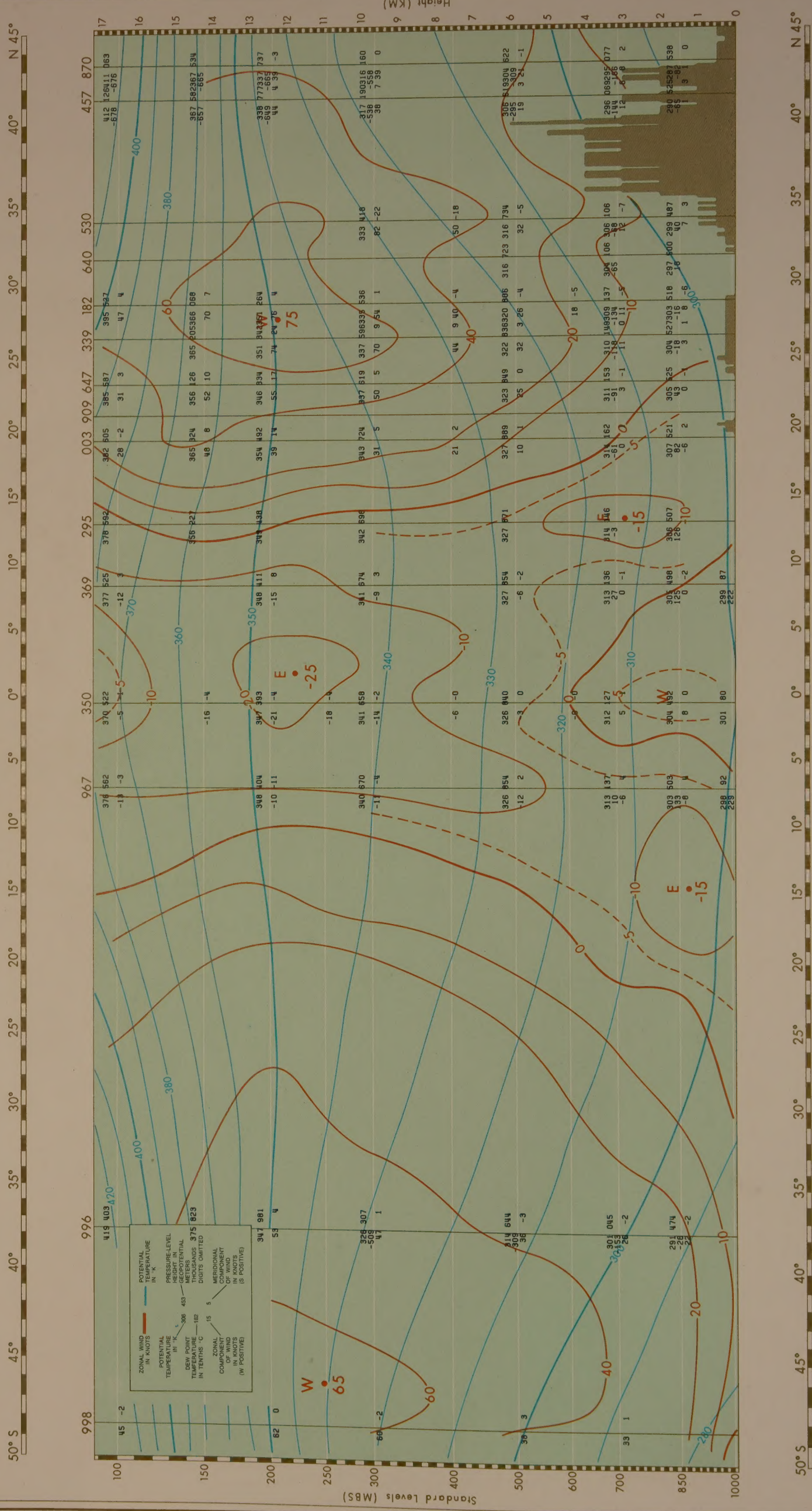
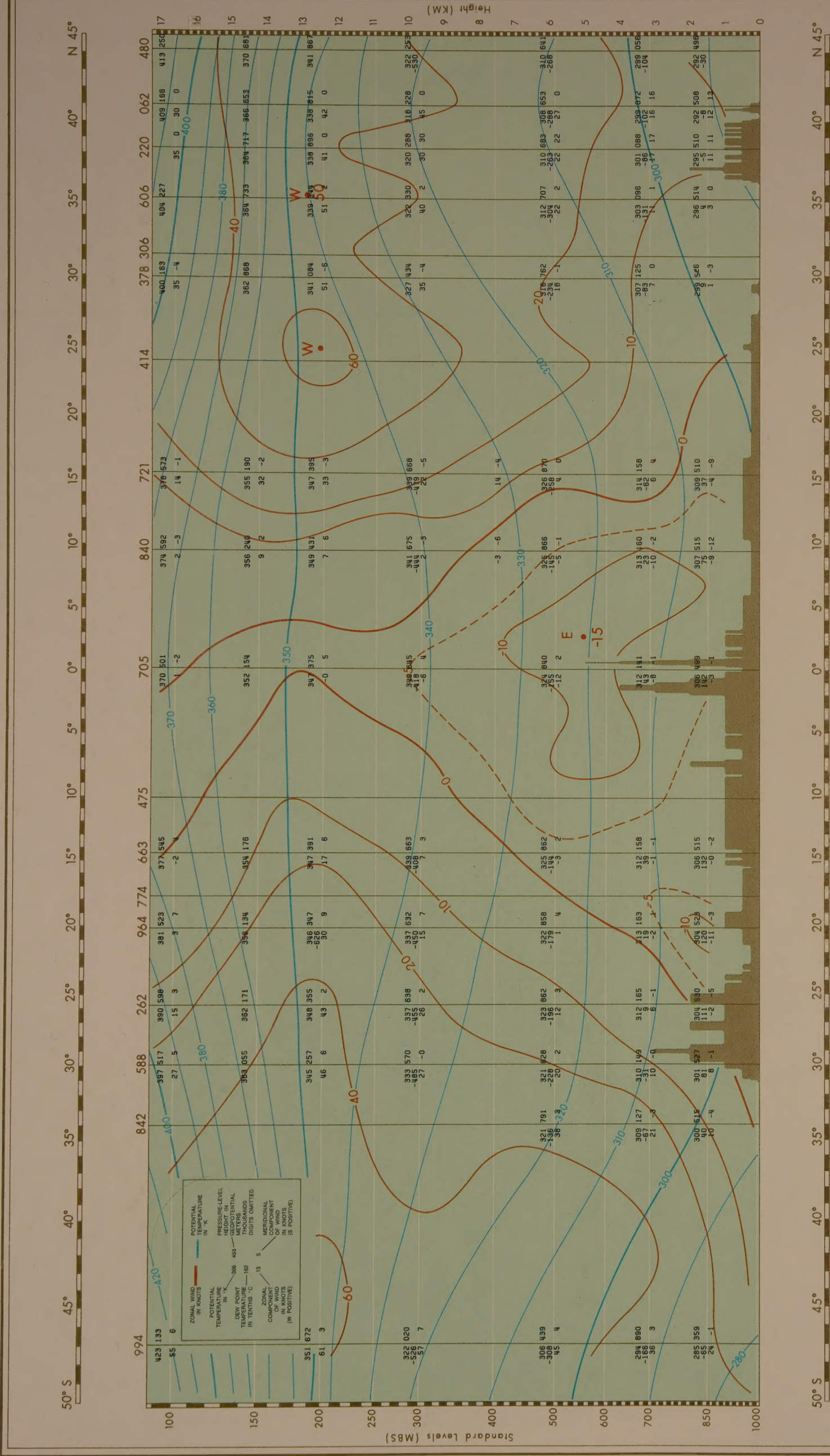


# NOVEMBER 100 mb Chart 107

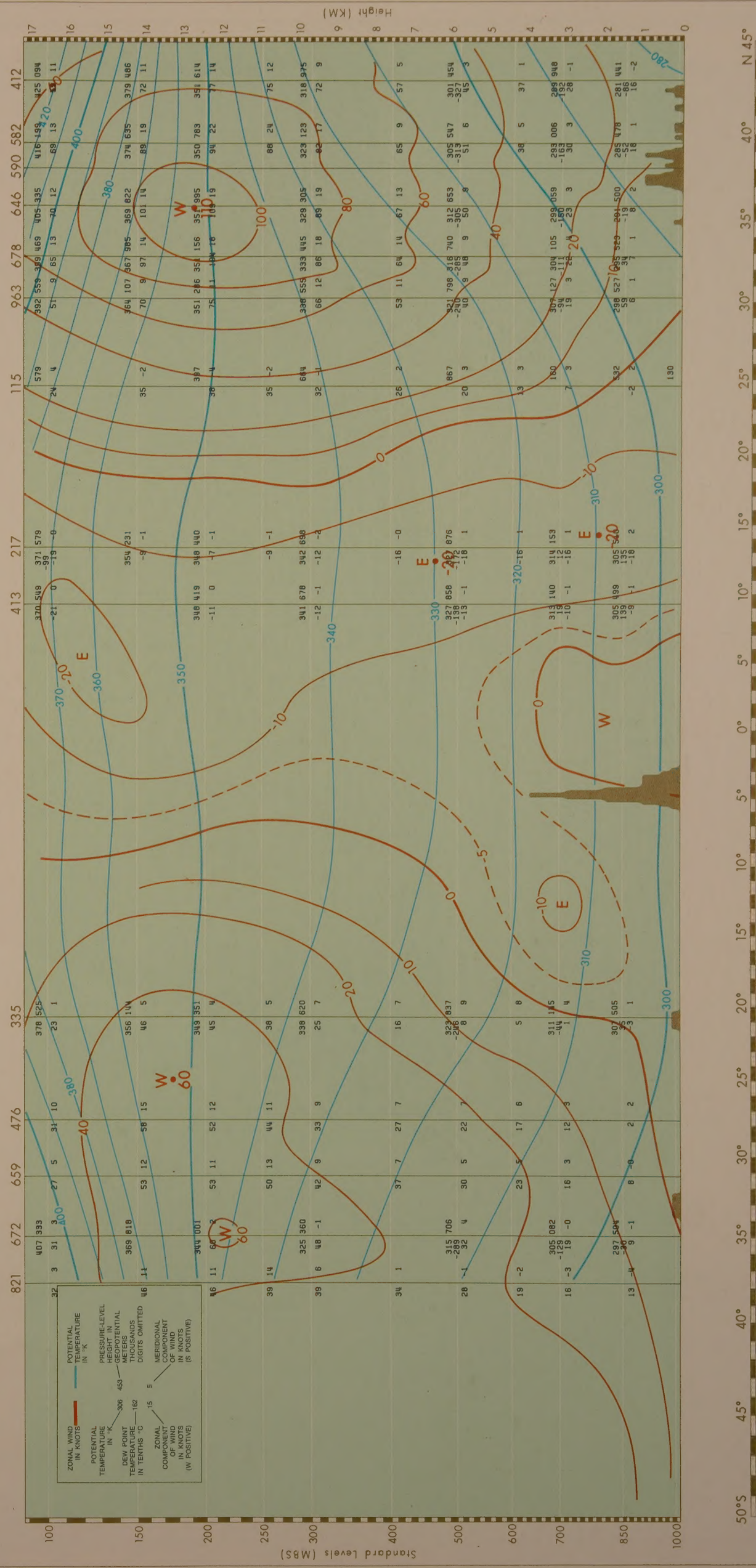
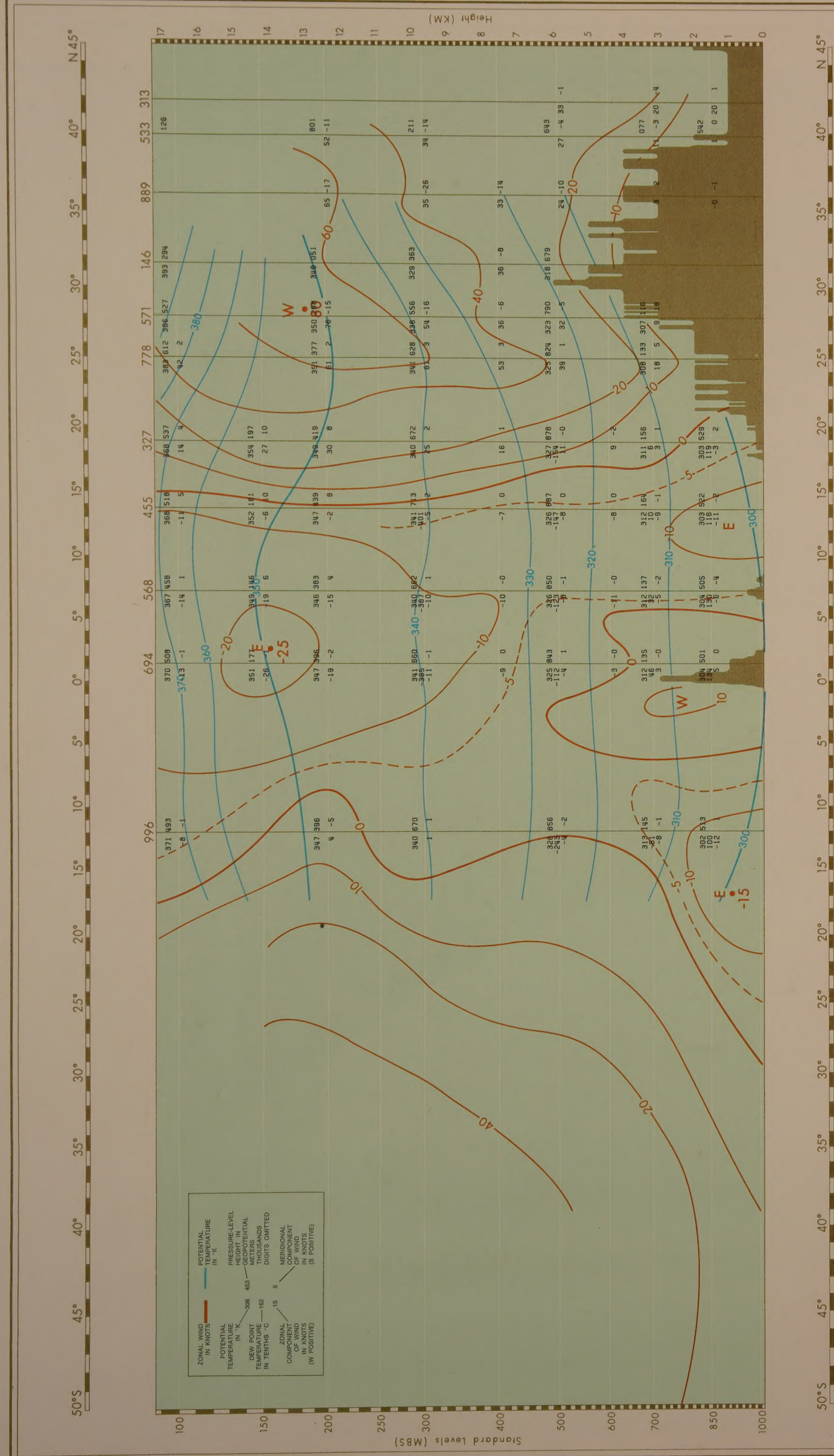




## NOVEMBER 30 E Chart 108

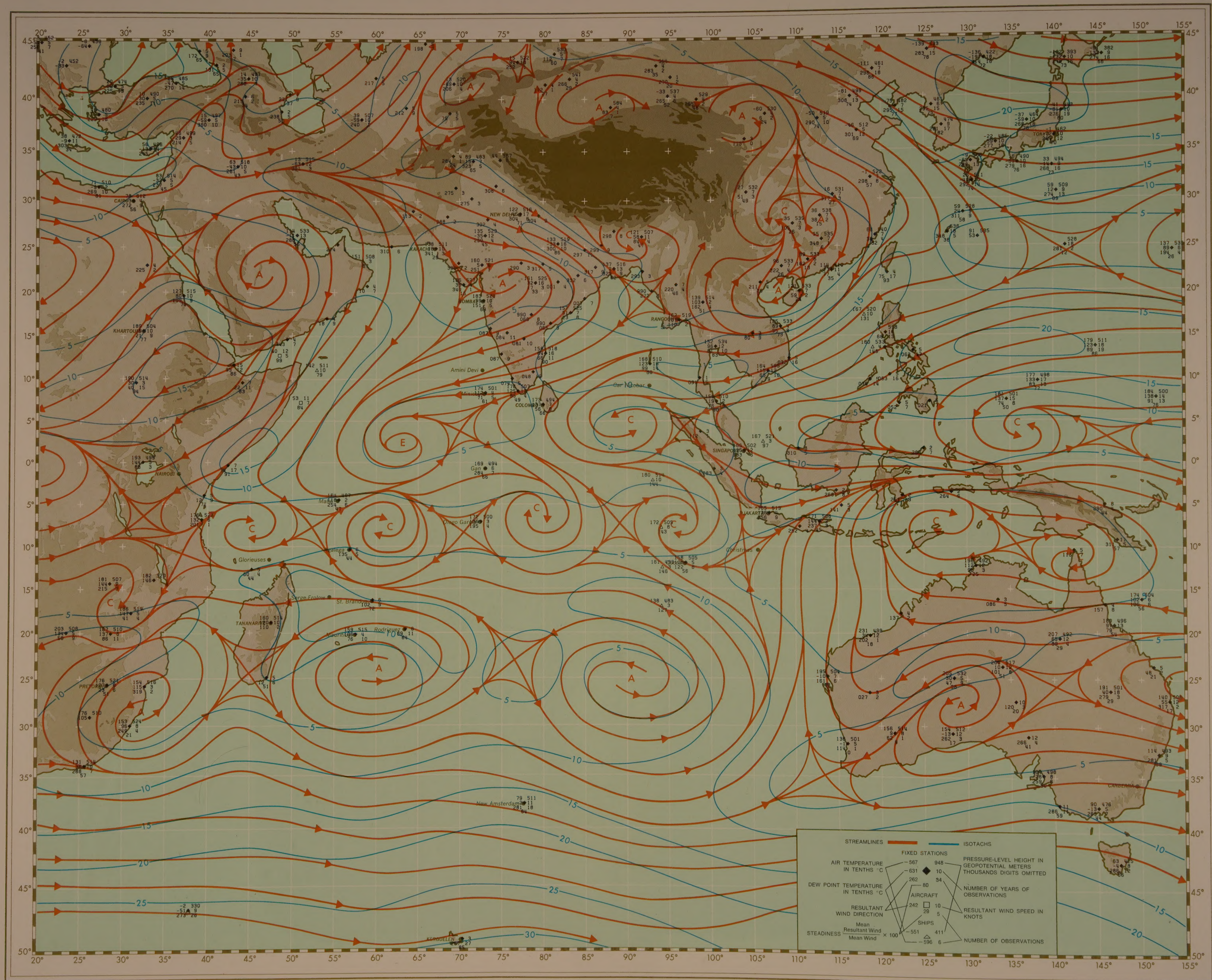






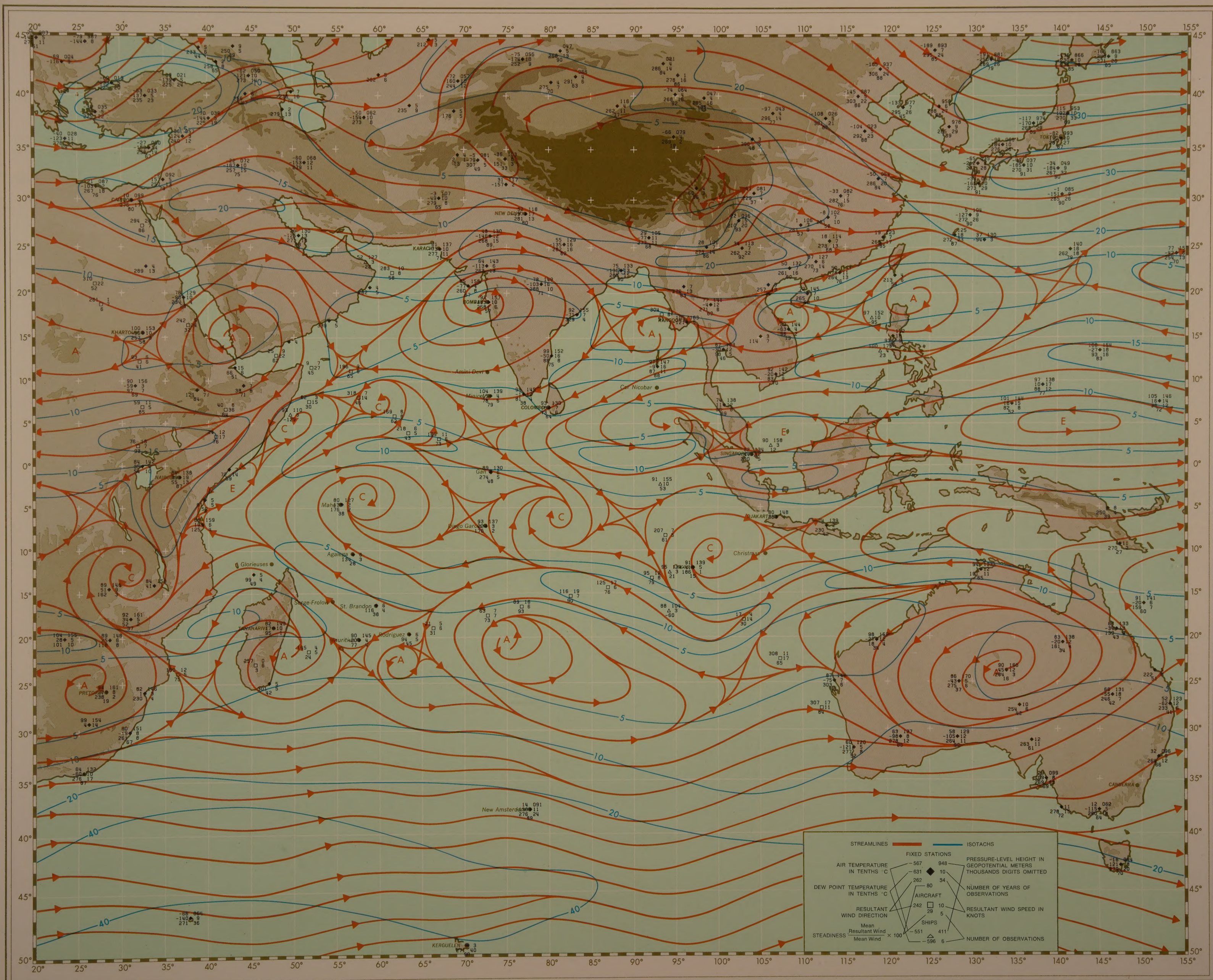


# DECEMBER 850 mb Chart 112



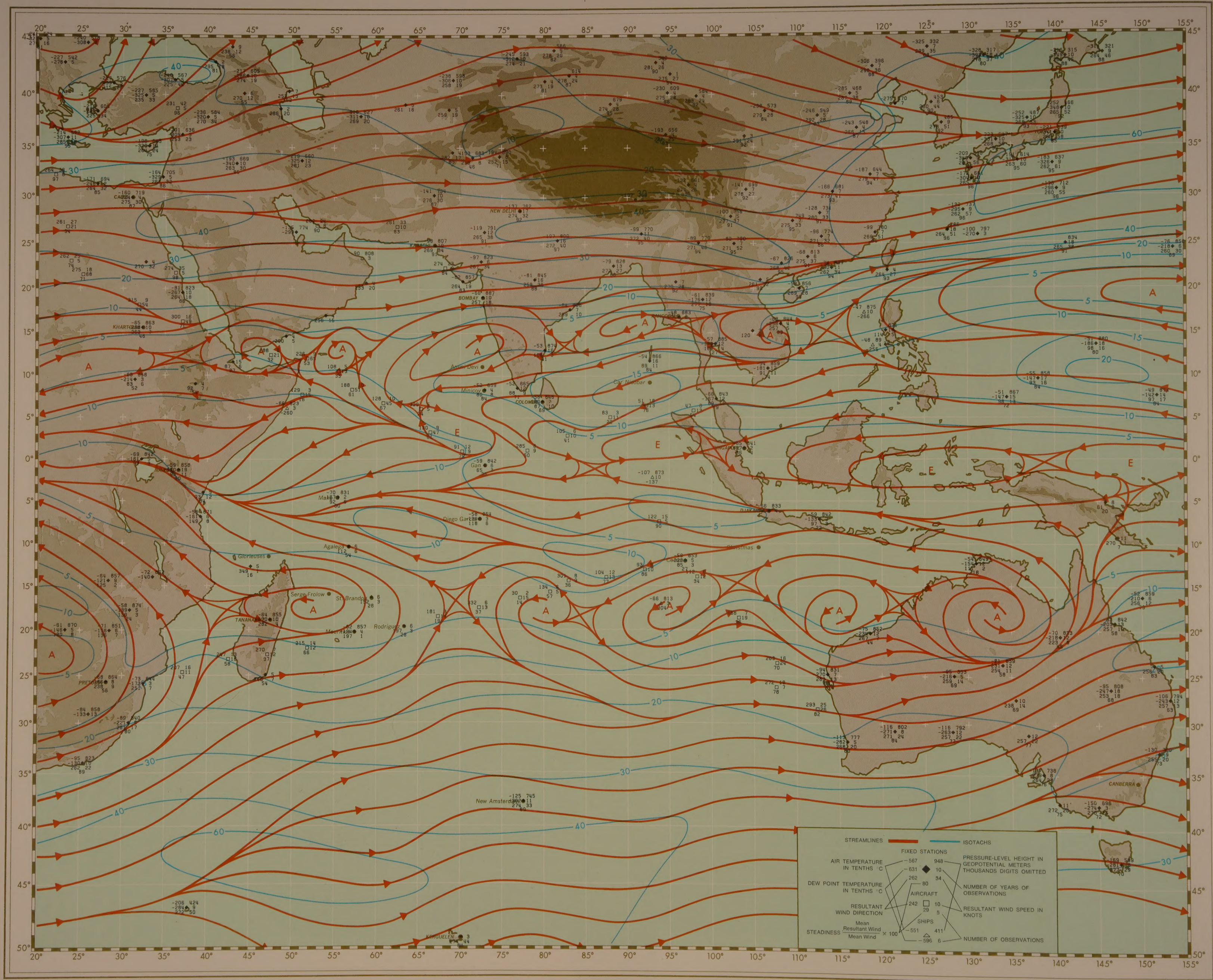


# DECEMBER 700 mb Chart 113



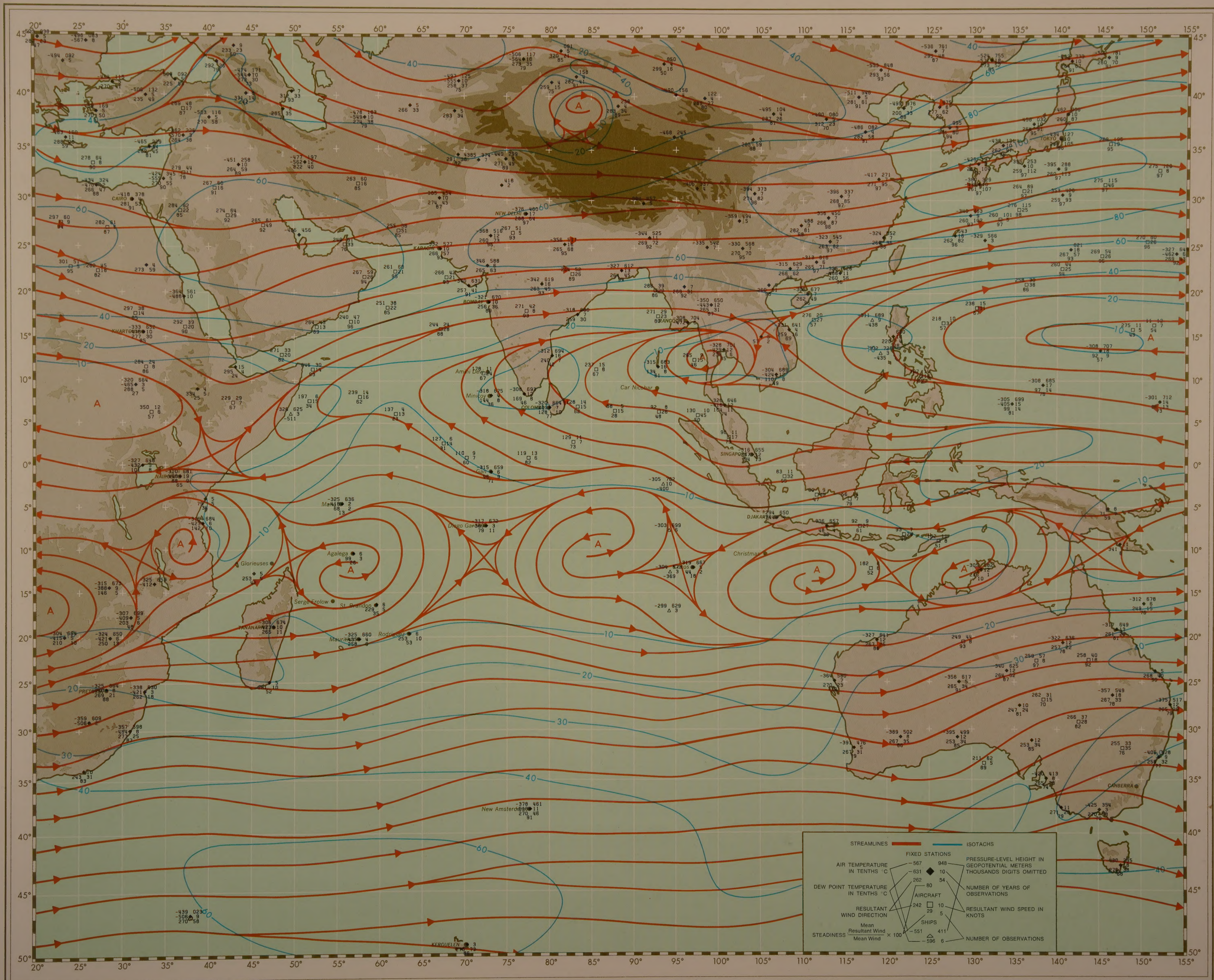


# DECEMBER 500 mb Chart 114





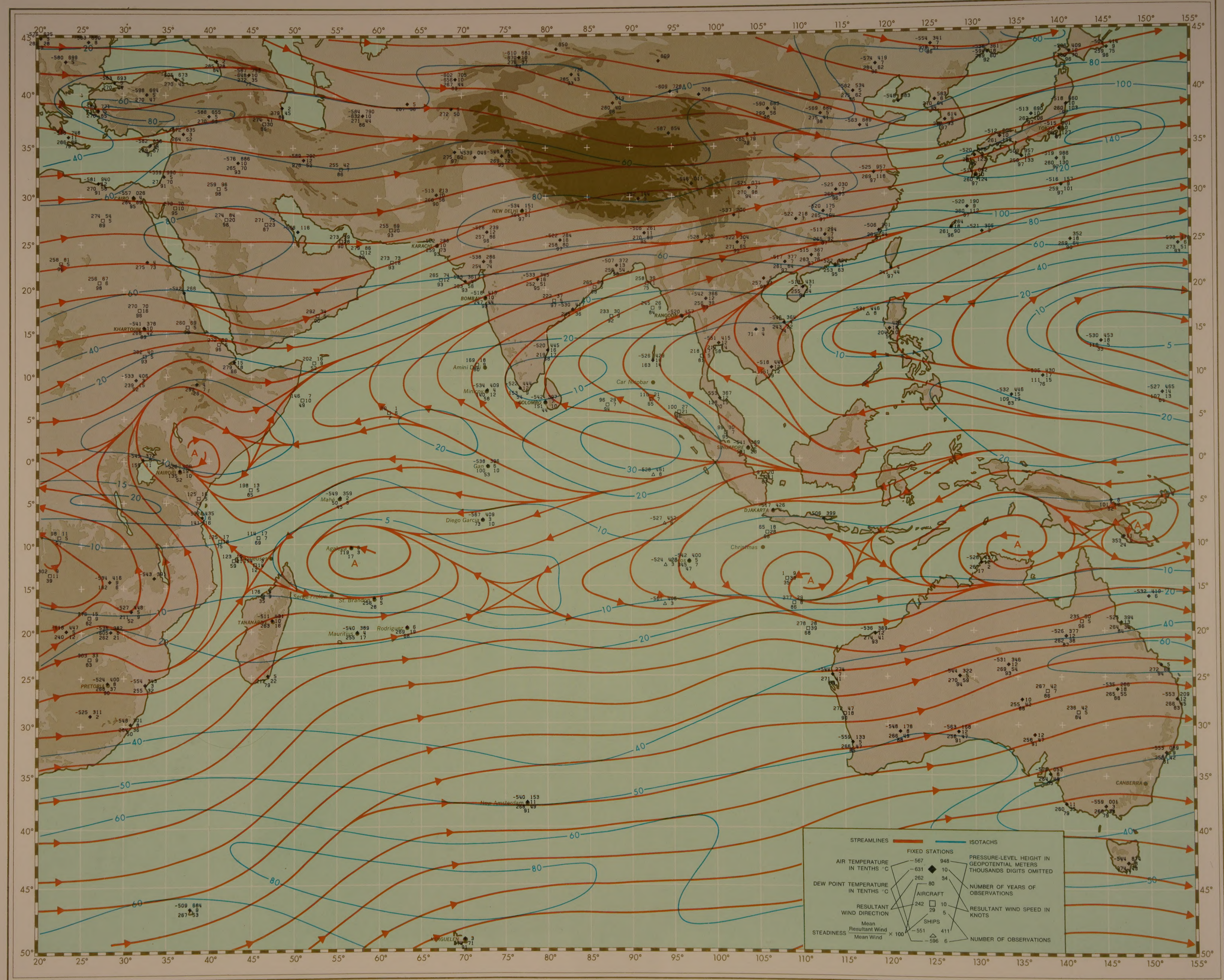
# DECEMBER 300 mb Chart 115



STREAMLINES — ISOTACHS  
 FIXED STATIONS — AIR TEMPERATURE IN TENTHS °C — DEW POINT TEMPERATURE IN TENTHS °C — RESULTANT WIND DIRECTION — MEAN RESULTANT WIND — STEADINESS — PRESSURE-LEVEL HEIGHT IN GEOPOTENTIAL METERS — THOUSANDS DIGITS OMITTED — NUMBER OF YEARS OF OBSERVATIONS — RESULTANT WIND SPEED IN KNOTS — NUMBER OF OBSERVATIONS

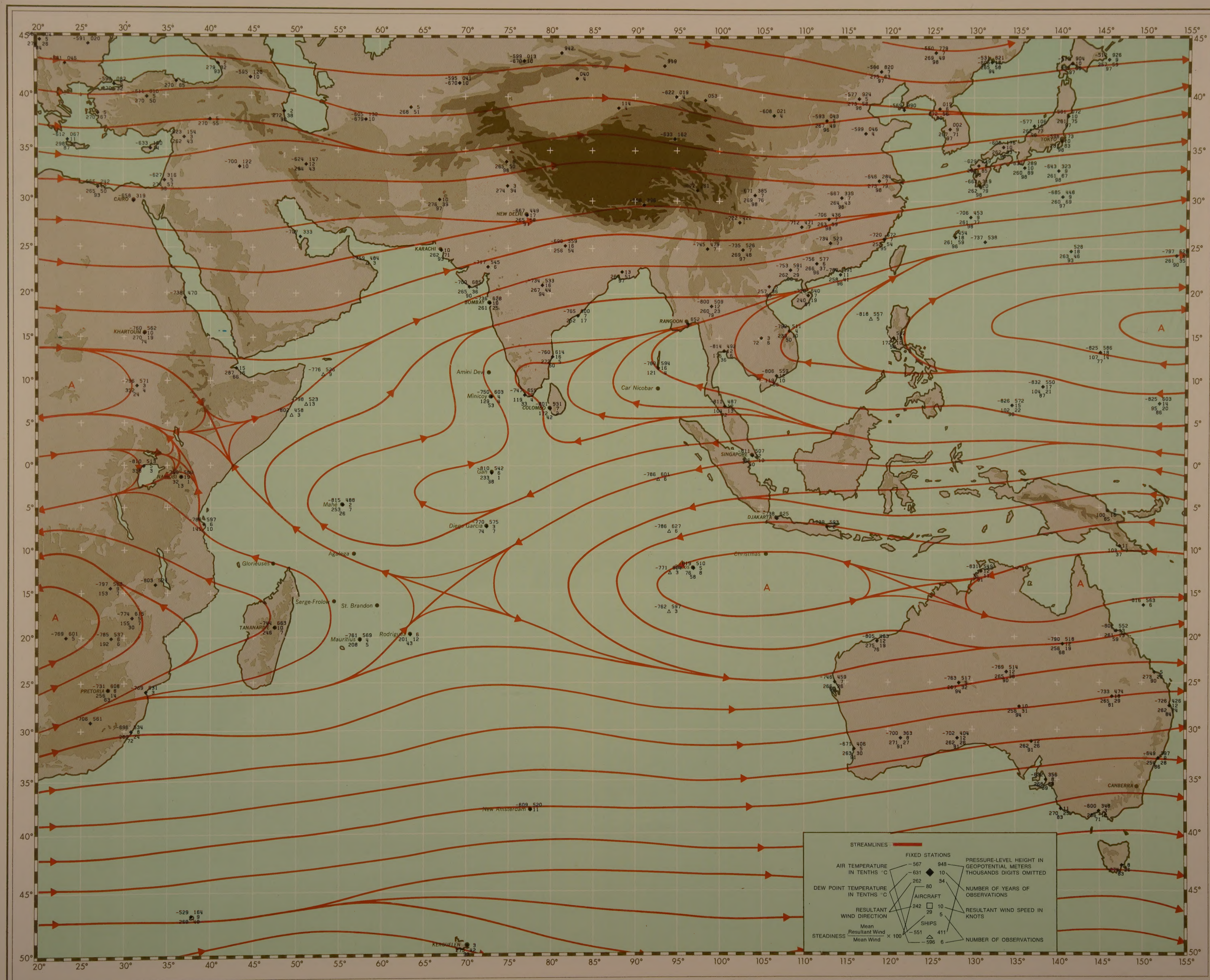


# DECEMBER 200 mb Chart 116





# DECEMBER 100 mb      Chart 117





# DECEMBER 30 E Chart 118

